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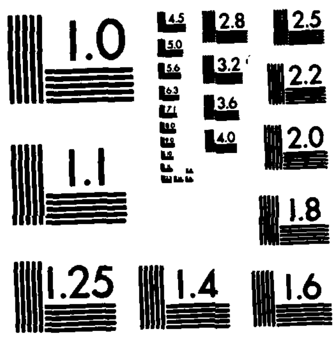

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Baltimore District

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Chesapeake Bay Low Freshwater Inflow Study Biota Assessment

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Volume I

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August 1980

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Phase II consists of a one-volume report and a supplementary MAP FOLIO.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Chesapeake Bay, Biology, Salinity, Habitat, Estuary

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An assessment of the effects of low freshwater inflow conditions on the biota of Chesapeake Bay was conducted through use of data output from the U.S. Army Corps of Engineers' Chesapeake Bay Hydraulic Model. Phase I of the biota assessment focussed on methodology development and establishment of a baseline for determination of freshwater inflow-induced change. Physical and chemical information, along with salinity tolerance and other habitat related information was collected for a group of over 50 study organisms.
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20. **ABSTRACT (continued)**

In Phase II of the assessment, four sets of hydraulic model test conditions (scenarios) were used which simulated effects of drought and effects of future consumptive water use as deviations from present average flow conditions. Changes in habitat for the selected study organisms were predicted and mapped based on salinity and other variables. Changes in habitat, which were used to delineate the amount of impact from reduced freshwater inflow, were found to include increases and decreases depending on the species, its lifecycle, tolerances, and interactions with other organisms. The magnitude of habitat change was found to generally increase as salinity changes increased.

CHESAPEAKE BAY LOW FLOW STUDY:

BIOTA ASSESSMENT

PHASE I: FINAL REPORT

VOLUME I

August 1980

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U.S. Army Corps of Engineers
Baltimore District
Chesapeake Bay Study Branch

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The authors wish to thank the members of the Baltimore District Corps of Engineers for their continual support throughout a very difficult process and their understanding during times of delay and confusion. In particular we with to thank Alfred Robinson, Noel Beegle, Steve Stegner, Linda Davidson and John Klein (the latter currently with EPA) of the Chesapeake Bay Study Branch of the Corps. The Corps' Steering Committee for the Chesapeake Bay Study has also provided both insight into difficult problems and many helpful suggestions.

At the outset of the study, WESTECH set up a team of experts termed an "anchor team" to assist by reviewing working documents and providing ideas and points of focus at our conferences. We wish to thank Alice J. Lippson, Donald Lear, Robert Otto, Louis Sage, J. Court Stevenson and Marvin Wass for their efforts on behalf of the project.

Special thanks also go to David Bastian and Marion Stevens at the Chesapeake Bay Model and Robert Norris and Norma Rowlins at the Potomac River Fisheries Commission for providing logistical support at our two conferences.

Many individuals, agencies and institutions helped by generously providing information, data and suggestions as the study progressed. The following is a partial list of the affiliations of the individuals who themselves are too numerous to mention:

U.S. Fish and Wildlife Service

U.S. Environmental Protection Agency

Region III Field Office

Chesapeake Bay Study

Maryland Department of Natural Resources

Fish and Wildlife

Tidewater-Fisheries

Water Resources

Coastal Resources

Power Plant Siting

Maryland Geological Survey

Maryland Environmental Health Administration

University of Maryland

Marine Extension Service

U.M. C.E.E.S. Labs

Chesapeake Bay Insitute, John Hopkins University

Smithsonian Institution

National History Museum

Chesapeake Bay Center

Old Dominion University

The American University

Virginia Institute of Marine Science

Virginia Marine Resources Commission

Virginia Fish and Game

National Marine Fisheries Service

Resource Statistics Division

Oxford Laboratory

CONTENTS

VOLUME I

VOLUME III
APPENDICES

LIST OF FIGURES

Page

LIST OF TABLES

I. PURPOSE AND SCOPE

This report is the product of Phase I of the Biota Assessment portion of the Chesapeake Bay Low Flow Study. The Chesapeake Bay Low Flow Study itself is part of the Chesapeake Bay Study being conducted by the U.S. Army Corps of Engineers. The relationship and projected timeframes of the Chesapeake Bay Study components are shown in Figure I-1. The Low Flow Study is one of the first in a series of special studies which will be directed at elucidating the effects of particular sets of environmental conditions on the Bay.

A. CHESAPEAKE BAY STUDY

In 1965, Congress adopted Section 312 of the River and Harbor Act which authorized the Secretary of the Army, acting through the Chief of Engineers to:

> ". . . make a complete investigation and study of water utilization and control of the Chesapeake Bay Basin. . ."

This investigation became known as the Chesapeake Bay Study. It was to include such subject areas as:

- navigation
- fisheries
- flood control
- noxious weed control
- water pollution
- water quality control
- beach erosion
- recreation

In addition, to carry out the purposes of Section 312, the Secretary, acting through the Chief of Engineers was authorized to construct a hydraulic model of the Chesapeake Bay Basin and an associated technical center.

Monies were appropriated and the Chesapeake Bay Study began in 1967 directed toward the overall goals of determining the most beneficial uses of the water related resources of the Basin. The three objectives of the study are to:

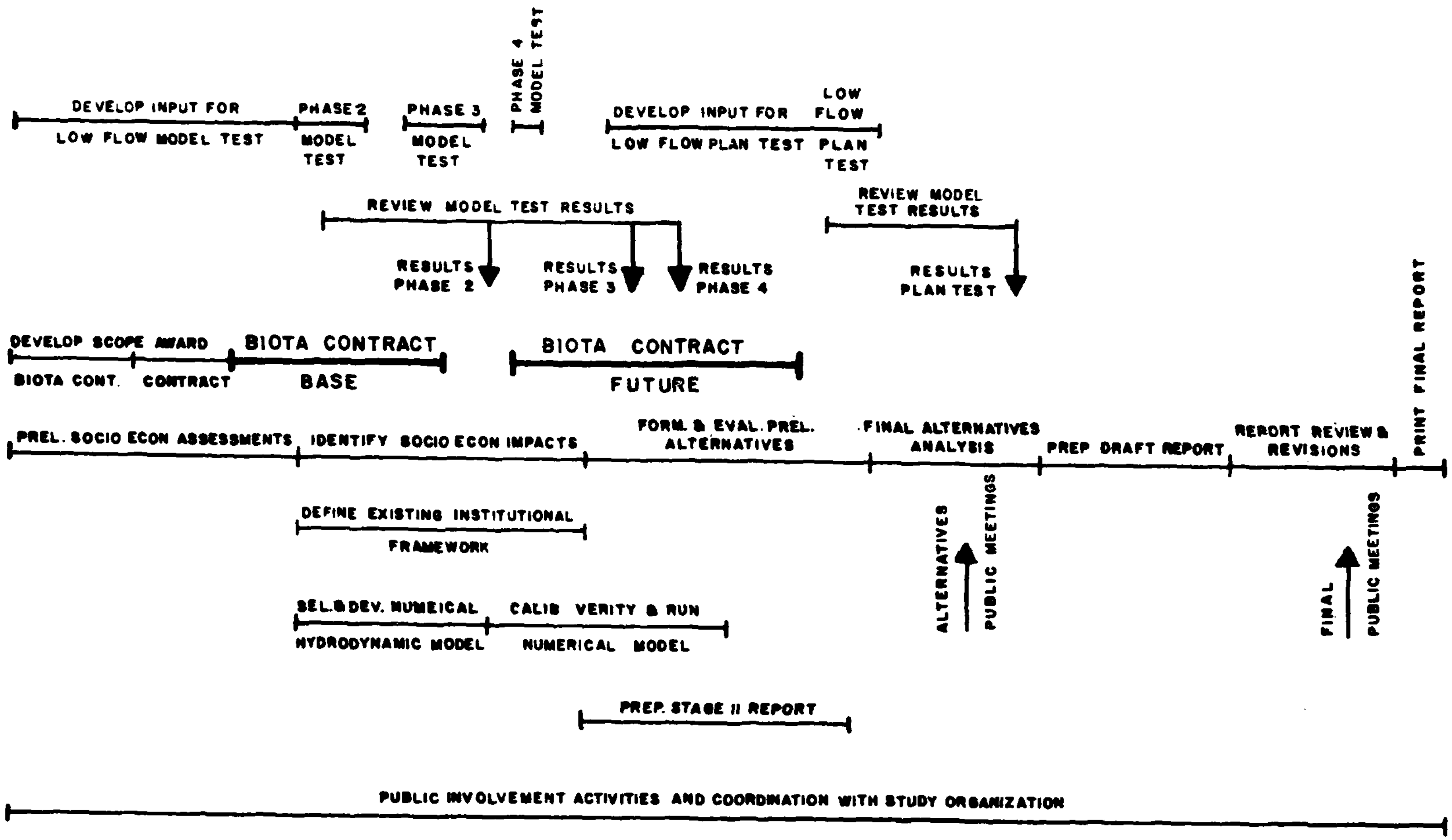


Figure I-1. CHESAPEAKE BAY STUDY COMPONENTS

Source: U.S. Army Corps of Engineers, Chesapeake Bay Study Branch

- Assess the existing physical, chemical, biological, economic and environmental conditions of Chesapeake Bay and its water-related resources.
- Project the future water resources needs of Chesapeake Bay to the year 2020.
- Formulate and recommend solutions to priority problems using the Chesapeake Bay Hydraulic Model.

An inventory of Chesapeake Bay Resources comprised the first stage of the study, resulting in a seven volume Existing Conditions Report, published in 1973. This report provided an overview of Chesapeake Bay resources and documented information directed toward satisfying the first of the three goals. The second goal spurred the compilation of the second major study document, the twelve volume Chesapeake Bay Future Conditions Report which documents future water and water resources needs of the Bay region. A special study was also undertaken as a result of Tropical Storm Agnes which disrupted many of the Bay's physical and biological processes in the early 1970's. That report has been published as Impact of Tropical Storm Agnes on Chesapeake Bay.

As a major tool to aid in the assessment of changes or impacts on the Chesapeake Bay, the Corps of Engineers constructed a 14 acre hydraulic model of the Bay on Kent Island, Maryland. Construction of the model began in 1973 and was completed in 1976. Following initial calibration, adjustment and verification, the model has been used to provide data on salinities, velocities, tidal elevations and currents under various situations of interest for a wide variety of government and public agencies.

B. CHESAPEAKE BAY LOW FLOW STUDY

During recent decades, the Chesapeake Bay (Figure I-2), has experienced several periods of drought or low river flow conditions. These periods have been accompanied by noticeable changes in the physical, chemical and biological conditions of the Bay; however, past research efforts have not been sufficient to

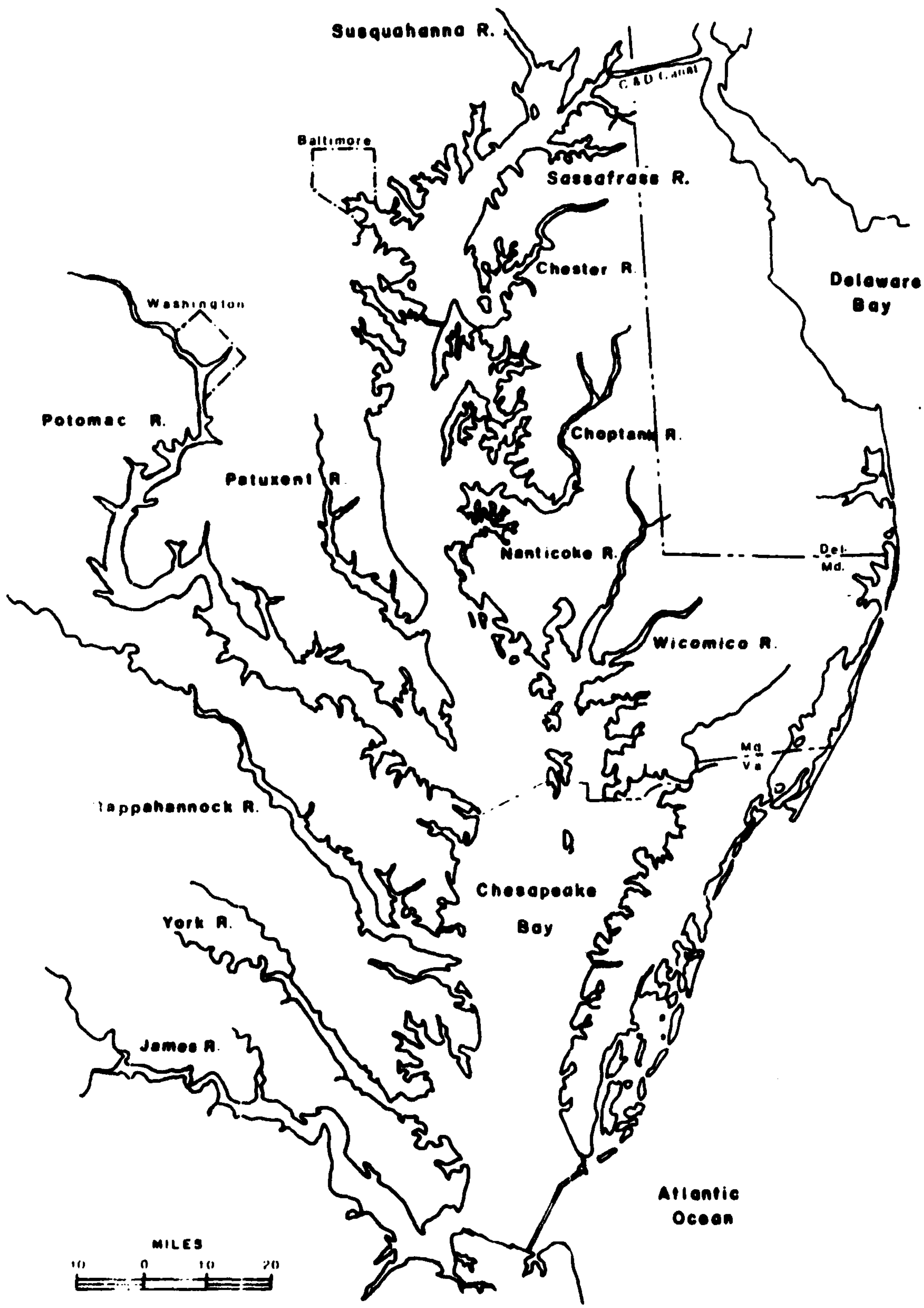


Figure I-2 CHESAPEAKE BAY AREA

establish quantitative or causal relationships between low flow and low flow effects. The most recent period of drought and low flows occurred during the period 1963 - 1965. The extend of this drought can be shown by comparison of total tributary flows with flow data from other, higher flow years (Figure I-3) and by salinity changes during 1960 and 1964 (Figure I-4).

In addition to drought, consumptive uses of water are expected to continue and increase in the Chesapeake Bay Region between the present time and the year 2020. Industrial, municipal and domestic water uses are made possible by diverting water from the Bay's tributary streams. While much of this water is recycled and returns to the system, less water is generally returned than the original amount diverted due to evaporation and other removal processes. This difference, or consumptive loss,is expected to increase as the Bay area population and its demand for water use expands during the next four decades.

The Summary volume of the Chesapeake Bay Future Conditions Report projects Bay-wide water service area supply deficits as increasing from levels of 72.5 mgd in 1980 to roughly 1045 mgd in the year 2020 (U.S. Army Corps of Engineers 1977). These supply deficits, which result in part from consumptive losses, can logically be expected to have the most severe effects on the Bay during low flow months, which typically occur during the summer and early fall.

As a focus for the joint concerns of drought and consumptive water use, the Corps of Engineers has undertaken a study to assess the effects of low flows on the Bay. The Corps, in connection with other agencies, is analyzing social and economic effects of low flows. A major component of this low flow study, the Biota Assessment, is being performed under contract to the Corps of Engineers by Western Eco-Systems Technology, Inc. (WESTECH), of which this report constitutes the methodologies and results of Phase I.

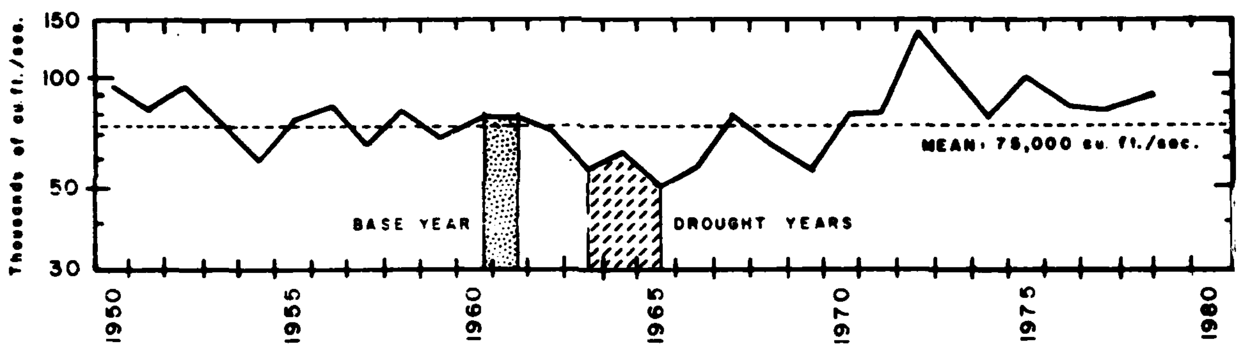
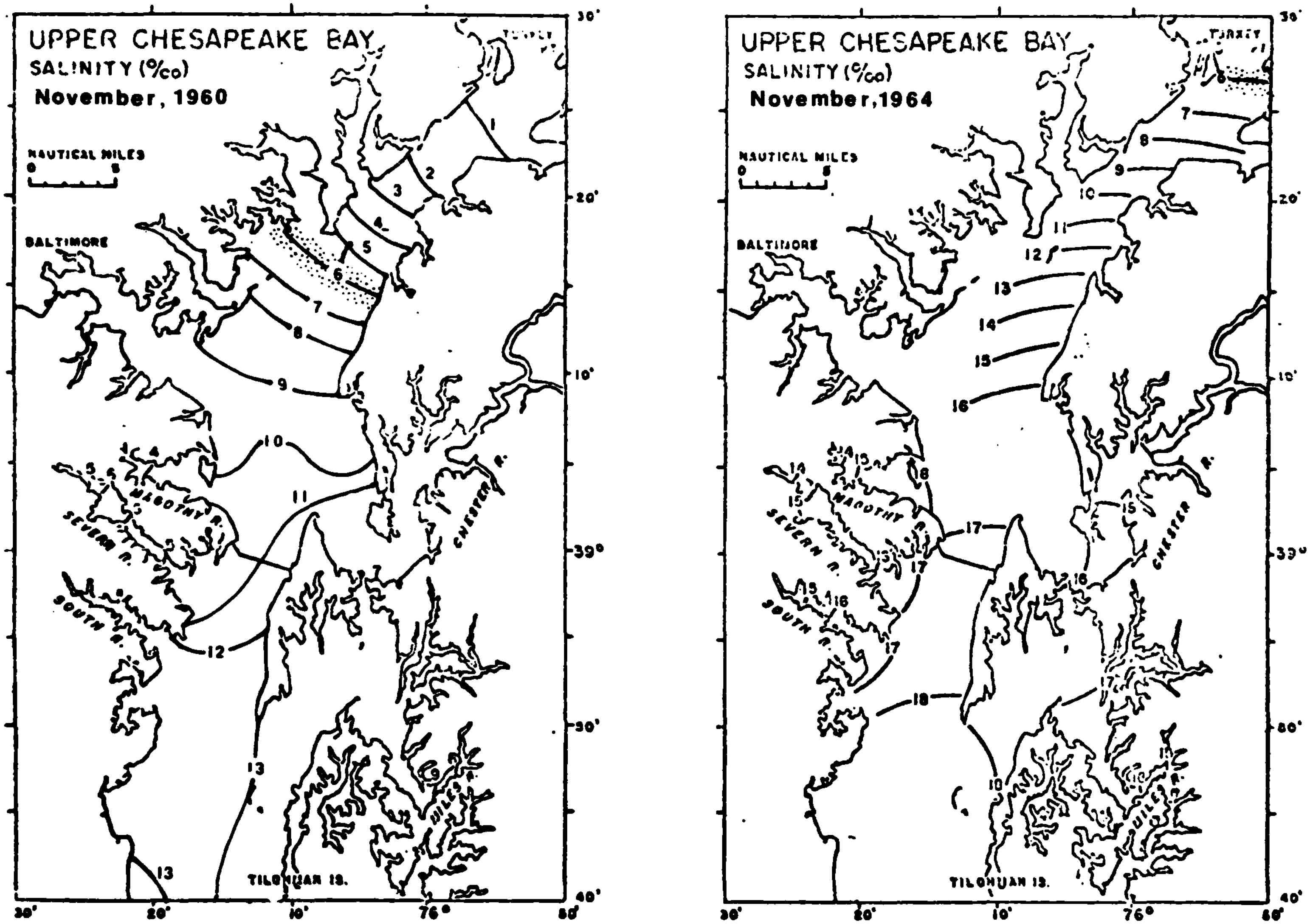


Figure I-3. AVERAGE STREAMFLOW INTO CHESAPEAKE BAY BY CALENDAR YEARS

Source: U.S. Dept of Interior, Geologic Survey, monthly streamflow summary



A. Salinities, Base year

B. Salinities, after low-flow period of summer and autumn

Figure I-4. **CONTRASTING SALINITY DISTRIBUTIONS IN THE UPPER CHESAPEAKE BAY**

Source Pritchard, 1966 ; Stroup and Lynn, 1963

The objectives of the Biota Assessment are:

- To define quantitatively (whenever possible), the biological relationships which govern the health and productivity of the Chesapeake Bay.
- To identify the effects of particular low flow conditions on biological organisms and relationships.

The Biota Assessment has been divided so as to accomplish these objectives in two phases.

1. Phase I - Establish Base Conditions and Assessment Methodolgy

Phase I of the Chesapeake Bay Low Flow Biota Assessment focuses on establishing a reference point for baseline environmental conditions and on developing methodologies for assessment of low flow effects. Establishment of baseline environmental conditions involves consideration of:

- patterns of physical and chemical parameters (particularly salinity),
- key biological species or species groups,
- distribution, range and abundances of key species,
- salinity tolerance of key species,
- biological productivity and diversity,
- inter-relationships between organisms (competition, predation, etc.),

as well as many other parameters. Due to the high variability of species range and abundance over time, base time periods of both salinity distribution and biological studies have been selected. It has become clear through discussions and seminars with numerous agencies and Bay area researchers that terms such as "Health" and "Productivity" when applied to Chesapeake Bay cannot be defined in absolute terms. They can, however, be defined in terms of a set of baseline conditions. Baseline conditions could include such possibilities as 1) a totally unpolluted pristine Bay, or 2) present Bay conditions or other assumed conditions. Since the bulk of existing biological, chemical and physical studies document present or recent conditions, this is the most reasonable baseline condition to deal with and was used for Phase I of this study.

The products to be developed in Phase I include:

- A list of study species.
- A map-atlas of study species distributions under base conditions.
- A synthesis of tolerance data for selected species.
- A model of species interactions of key Chesapeake Bay organisms.
- An assessment methodology to Phase II impact assessment.
- An accompanying textual report.

The map atlas has been generated on 1:250,000 scale mylar base maps and overlays and submitted to the Corps of Engineers. This atlas is not included with this report, although selected smaller scale examples of these maps are included in later chapters. The model of species interactions includes both a conceptual and mathematical model which are described in detail in Chapter VI. The mathematical model, designated the Chesapeake Bay Ecosystem Model (CBEM), has been implemented and stored on the University of Maryland's Univac 1108 computer system. The first six chapters of this report constitutes the overall methodologies and results of Phase I, while Chapter VII summarizes the impact assessment methodology which will be used in Phase II.

2. Phase II - Futures - Scenarios - Low Flow Impact Assessment

In preparation for Phase II of the Biota Assessment, the Chesapeake Bay Study Branch of the Corps of Engineers has conducted several flow tests using the Chesapeake Bay Hydraulic Model. The flow regimes have been selected to represent particular conditions of interest to the goals of the Low Flow Study and include:

- Average inflow Test (1960-1970 conditions)
- Drought scenario (1963-1966)
- Average inflow Test (2020)
- Consumptive Water Use Scenario with drought (2020)

The average infow test represents non-drought conditions and has been developed from weighted monthly average tributary flows over a 30 year period. The Corps of Engineers terms this weighted average a "modal hydrograph". The drought scenario consists basically of a set of flow conditions which reproduce the drought of the mid-1960's. The consumptive water use scenario represents a recurrence of the 1960's drought further reduced by projected consumptive losses for the year 2020. Data will be collected at various depths at over 200 stations located on transects of the Corps hydraulic model shown in Figure I-5. Further details on these scenarios and data is currently available from the Baltimore District of the U.S. Army Corps of Engineers and will be made part of the Phase II report to be published in 1981.

From the scenarios defined above, selected data on salinities velocities and tides will serve as input to the Biota Assessment in Phase II. Based on these data, impact assessments will be carried out on the key species and species groups identified in Phase I. Modeling and mapping of species distributions, productivities and interactions under the various scenarios will form the thrust of the products to be generated in Phase II. The controlling influences of salinity and flows will be examined as providing the primary physical generators of scenario impacts.

C. REPORT ORGANIZATION

The chapters below detail WESTECH's methodologies and findings during Phase I of the Biotic Assessment portion of the Low Flow Study. Chapter II outlines the steps involved in carrying out this rather massive synthesis of major Bay data sources and the techniques used for sifting these data for the elements most vital to accomplish Low Flow Study objectives. The third chapter gives a brief and somewhat superficial overview of the major pieces of literature on four important areas of knowledge which are necessary to the understanding of the later chapters.

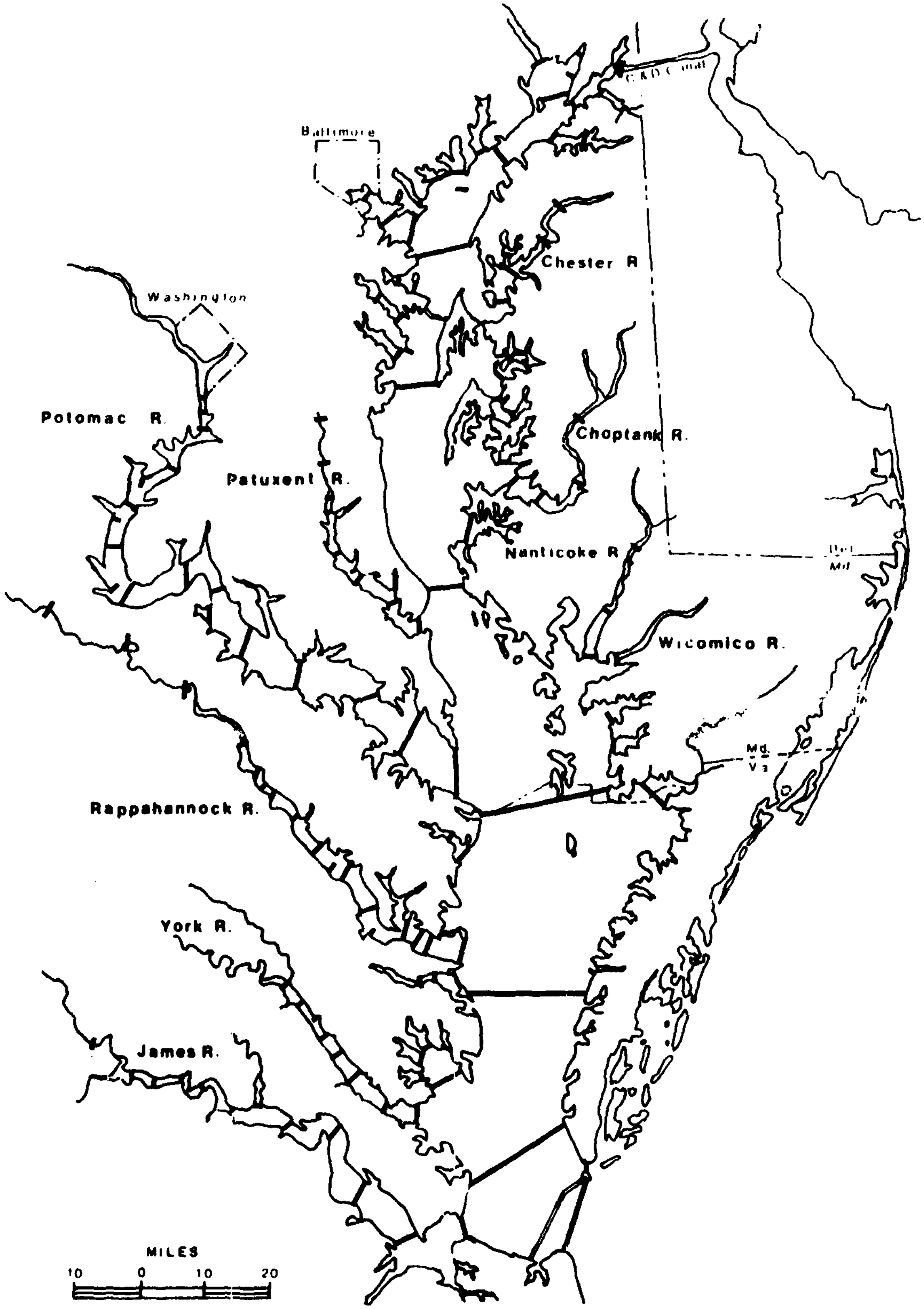


Figure I-5. MAJOR SALINITY TRANSECTS OF THE CHESAPEAKE BAY MODEL

Source: U.S. Army Corps of Engineers, 1979

Chapter IV sets out the parameters and systems used to define base conditions in the Chesapeake Bay. By discussing the environmental variables, this chapter lays the groundwork for discussion of the species themselves in Chapter V. The fifth chapter shows the process of selecting "key" or "study" species and relates these to the environmental parameters.

Chapter VI first begins with the conceptual modeling of known relationships between the study species and groups. These relationships are then further elucidated through use of mathematical modeling. The chapter concludes with discussion of effects of altered salinity conditions based on the modeling, and identifies important gaps in the current data base.

Chapter VII discusses the approaches to Phase II impact assessment based on the results of the first Phase. This chapter places the Phase I results in perspective and functions to develop the conclusions outlined in Chapter VIII.

CHAPTER I. REFERENCES

U.S. Army Corps of Engineers. 1973. Chesapeake Bay Existing Conditions Report. Baltimore District, Baltimore, MD.

U.S. Army Corps of Engineers. 1975. Impact of Tropical Storm Agnes on Chesapeake Bay. Baltimore District, Baltimore MD.

U.S. Army Corps of Engineers. 1977. Chesapeake Bay Future Conditions Report. Baltimore District, Baltimore, MD.

U.S. Army Corps of Engineers. 1979. Unpublished report on salinity transects. Baltimore District, Baltimore, MD.

II. STUDY METHODOLOGY

This chapter constitutes an explanation of the steps and major tasks pursued in the completion of Phase I of the Biota Assessment It provides both a background on which to judge the completeness and validity of the research conclusions and a synoptic picture of the rationale involved in the development of the major work products. The chapter proceeds from discussion of information sources (literature and professionals) through species classification, development of assessment methodology and mapping of species distribution.

A. LITERATURE SEARCH

The initial subtask of the biota assessment was the compilation of a bibliography of studies of living organisms inhabiting Chesapeake Bay and the factors affecting their distribution and abundance. The bibliography was not limited to studies conducted in the Bay but also included studies of Chesapeake organisms done in other estuarine areas. This compilation was made using computerized bibliographical and abstracting services supplemented by intensive manual searches of journals and other sources.

Computerized bibliographies have the advantage of rapid listing of information. Disadvantages of computer searches include the possibility of missing relevant citations due to limited key word requests and the fact that much useful information resides in reports and documents not considered publications by the maintainers of the computer files. For this reason, computerized literature searches were conducted first to roughly define the body of literature available with full knowledge that much important work would not be discovered.

Computerized files searched in this phase were:

- Biological Abstracts
- Oceanic Abstracts
- Pollution Abstracts
- Environmental Abstracts
- Dissertation Abstracts

Of these, Oceanic Abstracts yielded the largest number of titles and Pollution Abstracts yielded the fewest.

In addition to the listings of publications provided by the abstracting services, published bibliographies were consulted.

The most useful published bibliographies were:

- Hopkins, S.H. 1973. Annotated Bibliography on Effects of Salinity and Salinity Changes on Life in Coastal Waters. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.
- Stevenson, J.C. and N.M. Confer. 1978. Summary of Available Information of Chesapeake Bay Submerged Vegetation. Contract # FWS 14-16-0008-2138, U.S. Fish and Wildlife Service.
- The National Technical Information Service. Published Searches of Ecology in the Marine Environment. Volumes 1 - 5 used to identify the many government-sponsored research reports. Several otherwise unavailable reports were ordered through NTIS.
- Virginia Institute of Marine Science. 1972 - 76. Chesapeake Bay Bibliography. Volumes I-IV.

The largest single source for citation of the"gray"literature (technical reports) has been the four volume Chesapeake Bay Bibliographies published as special scientific reports by the Virginia Institute of Marine Science. For some specific organisms published bibliographies are also available. These were consulted as needed.

A computerized bibliographical search depends upon the thoroughness of the topic headings searched. The initial topic headings searched include:

- Chesapeake Bay
- productivity
- salinity
- carbon fixation
- chlorophyll
- ecological communities
- submerged aquatic vegetation
- grasses
- biota
- production
- photosynthesis
- respiration
- metabolism
- waterfowl

- phytoplankton
- zooplankton
- benthos
- water quality
- temperature
- fisheries
- fish populations
- names of individual organisms (e.g. oysters, crabs, copepods)

Subsequent to the compilation of references based on the computerized search of key words a manual search of journals was initiated. Journals, reports to government agencies and industry, books, symposia proceedings, theses and dissertations were systematically searched for potentially useful information. The search began with the most recent sources and proceeded backwards through the 1970's. In many cases issues further in the past were searched depending on the usefulness and number of papers found. For example, every issue of Chesapeake Science was examined from the beginning of the publication. Table II-1 lists the major journals searched. Copies of each relevant article were catalogued and placed in binders according to subject. In addition, important journal articles were derived from the "literature cited" section of recent publications. These, combined with articles selected by computerized key words were found to comprise a comprehensive body of relevant literature.

The following libraries have been searched, particularly for publications specific to each institution or agency:

- Virginia Institute of Marine Science
- Patuxent Wildlife Research Center
- American University
- University of Maryland
- The Smithsonian Institution - National History Museum
- National Marine Fisheries Service (Central Library)
- Interior Department
- Hornpoint Environmental Laboratory
- Chesapeake Biological Laboratory
- Chesapeake Bay Center

TABLE II-1

Major Journal and Serials Searched During Literature Collection

Advances in Marine Biology
American Naturalist
American Journal of Botany
Annual Review of Ecological Systematics
Aquatic Botany
Biological Bulletin
Bulletin of Marine Science
Chesapeake Science
Chesapeake Biological Laboratory Contributions
Ecology
Ecological Modeling
Estuaries
Estuarine and Coastal Marine Science
Fishery Bulletin
Hydrobiological Journal
International Revue ges. Hydrobiologie
Journal of Ecology
Journal of Experimental Marine Biology and Ecology
Journal of the Fisheries Research Board of Canada
Journal of Marine Research
Journal of Marine Science
Journal of the Marine Biological Association of the United Kingdom
Journal of Phycology
Journal of Wildlife Management
Limnology and Oceanography
Marine Biology
National Fisherman
Oceanography and Marine Biology Annual Review
Transactions of the American Fisheries Society
Transactions of the North American Wildlife Conference
Proceedings of the National Shellfisheries Association
Virginia Institute of Marine Science Contributions

- Chesapeake Bay Institute
- Johns Hopkins University
- Library of Congress Dissertation Collection

In many cases, searches of these libraries produced little-known or unpublished information which was releasable by the agency or institution.

The U.S. Army Corps of Engineers Chesapeake Study Branch provided WESTECH with copies of numerous major government reports and reprints of over 60 papers and journal articles related to the project. These reprints were material used by the Corps to define the background of the problems and tasks to be addressed by the biota assessment.

From the initial bibliographies, reprints were collected of those publications not already available in the WESTECH library. This was followed by the collation and assimilation of the literature employing the compiled bibliography. WESTECH's interdisciplinary approach required that each staff biologist or ecologist read the accumulated papers in their area of specialization and select for others to read the most significant papers on a given subject. Where information was not available in the published and "gray" literature, other sources were sought.

B. CONTACT OF BAY RESEARCHERS

Drawing on the personal knowledge of the WESTECH staff, Corps of Engineers staff, and the Chesapeake Research Consortium's Chesapeake Bay Directory, a systematic schedule of contacts was initiated with the Government agencies, academic institutions and private firms which have active interest in research on Chesapeake Bay. Researchers were asked about ongoing research, research completed but not yet published, and related projects which they felt might have a contribution to the understanding of the impacts of low fresh water inflows. Nearly 100 individual scientists were contacted from the institutions listed in Table II-2.

TABLE II-2.

Contact with Chesapeake Bay Researchers

Institution	Type	Number of Persons Contacted
American University	Educational	3
Anne Arundel Community College	Educational	1
Benedict Estuarine Research Laboratory of the Philadelphia Academy of Sciences	Contract Research	5
Chesapeake Bay Institute, Johns Hopkins University	Educational	4
Chesapeake Biological Laboratory, University of Maryland, Center for Estuarine and Environmental Studies	Educational	6
Division of Fish and Wildlife-Delaware	State Government Agency	1
Environmental Technology Center of Martin Marietta Corporation	Contract Research	2
Environmental Protection Agency Region III and Chesapeake Bay Study	Federal Government Agency	5
Environmental Health Administration, Maryland Department of Health and Mental Hygiene	State Government Agency	3
Fish and Wildlife Service, U.S. Department of Interior	Federal Government Agency	6
Department of Biology, George Washington University	Educational	1

TABLE II-2. (Cont.)

Contact with Chesapeake Bay Researchers

Institution	Type	Number of Persons Contacted
Horn Point Laboratory, University of Maryland, Center for Estuarine and Environmental Studies	Educational	5
Institute of Marine Science, University of North Carolina	Educational	1
Maryland Academy of Sciences	State Government Agency	1
Maryland Geological Survey	State Government Agency	5
Marine Science Consortium	Educational	1
Johns Hopkins University	Educational	3
National Marine Fisheries Service	Federal Government Agency	2
Old Dominion University	Educational	5
Power Plant Siting Program, Maryland Department of Natural Resources	State Government Agency	2
Smithsonian Chesapeake Bay Center	Educational	3
Tidal Fisheries Division, Maryland Tidewater Administration	State Government Agency	5
U.S. Geological Survey	Federal Government Agency	2
University of Maryland, Baltimore Campus	Educational	1

TABLE II-2. (Cont.)

Contact with Chesapeake Bay Researchers

Institution	Type	Number of Persons Contacted
University of Maryland, College Park Campus	Educational	5
Virginia Institute of Marine Science	Educational	10
Virginia Fish and Game	State Government Agency	2
Water Resources Administration Maryland	State Government Agency	4
Water Resources Administration Virginia	State Government Agency	2
Wildlife Administration, Maryland Department of Natural Resources	State Government Agency	1
Unaffiliated individuals		3

Personal contact brought to light the existance of maps, surveys, unpublished data files and notebooks which served as valuable sources of information in many cases, particularly with respect to the distribution of organisms. Computer data banks which were consulted include;

- EPA STORET: 2515 station of approximately 19 parameters covering location, temperature, depth, tide stage, conductivity, salinity, D.O., NO_2, NO_3, pH, As, Cd, Cr, Cu, Pb, Ar, NH_4, fecal coliform, and PO_4.

- NOAA: National Ocean Data Center archives listing of 384 hydrological stations within Chesapeake Bay, covering date, time, depth, location, temperature, salinity, and density.

- NOAA Environmental Data File (ENDEX): a listing of 10,099 data files containing biological information on the Chesapeake Bay and neighboring water bodies. These include file content description, geographical area covered, contact point for file access, file access restrictions and archival structure.

- MD. D.N.R. Power Plant Siting Program; Chesapeake Bay Oceanographic Data Base: 358,290 observations taken at 4,381 hydrological stations covering the years 1939 through 1974. Parameters include time, date, location of sampling, depth, collecting agency, sampling method, temperature, salinity, dissolved oxygen, pH, alkalinity, chlorophyll a, suspended solids and secchi depth.

- MD. Water Resources Administration - Water Quality Data file: currently containing 50,000 observations from 3,000 stations, not all of which are sampled regularly. Coverage runs from 1970 through the present with regular updates. Variables include nutrients, heavy metals, oil and grease, and other pollutants, up to a total of 119 possible different substances.

Contact with Bay researchers has continued and is continuing throughout the biota assessment project. This is also true of the collection of literature, as new papers of interest continue to be published. Discussion with other researchers provides an excellent means of evaluating the completeness of the literature search subtask. A concern expressed repeatedly in discussions with other scientists is the large amount of unknown information concerning the life histories and physiological responses of many organisms within the estuary. A list (Appendix A, Tables A-1 & A-2) of unpublished or in-progress studies potentially applicable to the low flow biota assessment give some idea of the range of work which remains to be done.

C. SEMINARS

Syntheses of particular literature topics were developed into draft working papers according to the critical-path outline developed for the first phase of the project. Each working paper was then subject to rigorous sequential review and public discussion. The first review was conducted by a panel of knowledgeable Bay researchers, known as the Anchor Team. The WESTECH Anchor Team consists of:

- Donald Lear
- Alice J. Lippson
- Robert Otto
- Louis Sage
- J. Court Stevenson
- Marvin Wass

Public participation and review is an important and integral aspect to the development of WESTECH reports. This involvement of interested outsiders was deliberately encouraged by the provisions of two seminars during the first phase of the biota assessment contract. Working papers which had been reviewed by the Anchor Team (without yet incorporating reviewers modifications), were presented at these seminars.

The first seminar was held on November 15th at the Chesapeake Bay Hydraulic Model in Matapeake, Maryland. The working papers presented at that meeting covered:

- The criteria which WESTECH had developed for the selection of indicator species, and

- The definition of the "Health and Productivity" of Chesapeake Bay.

An announcement for the seminar was sent to 150 persons, representing education and research organizations, regulatory agencies, and conservation groups in the four adjacent states and the District of Columbia.

The second seminar was held on March 20th at the Potomac River Fisheries Commission in Colonial Beach, Virginia. The working papers presented at that seminar were:

- Habitat Classification, Species Selection and Salinity Tolerances,
- Impact Assessment Methodology, and
- Ecosystem Energy Flow Modeling.

Discussions followed each paper. Announcements to the seminar were mailed to nearly 200 persons from an expanded version of the first conference mailing list.

In addition to interaction through the seminars, review and commentary were received from the Corps of Engineers, the Steering Committee of the Corp's Chesapeake Bay Study, and the Fi[illegible]d Wildlife Service - Annapolis Field Office.

D. DEFINITION AND USAGE OF HABITATS

The Chesapeake Bay Biota Assessment is predicated on the idea that understanding of the estuarine system requires a knowledge of the major organisms on a species by species basis. To acquire this knowledge it was necessary to select a set of organisms designated "study species" which were to be studied in detail. Section E (below) discusses the process of selecting study species from all the possible organisms. Here, we discuss the corollary idea of organism habitat and habitat classification.

Due to the range of different types of organisms being studied, development of one, comprehensive habitat classification system proved to be an extremely complex task. Parameters which affect the distribution of attached plants and sessile benthos are usually not the parameters important to either planktonic or nektonic organisms. Several classification schemes were considered, each suitable for particular groups of organisms before a compatible set of parameters was reached. The background and rationale for the habitat classification used will be presented in Section V-E.

Figure II-1 is a generalized half cross-section of an estuary showing habitats defined by depth (wetland, shallow, mid-depth, deep and channel), bottom orientation (benthic, pelagic), and presence or absence of organisms (submergent or emergent aquatic vegetation, mud flat, oyster bar). Not shown on Figure II-1 are the physical and chemical parameters which can also define a habitat for a given species: tidal velocities, net flows, turbulance, turbidity, dissolved oxygen, sediment type, temperature and salinity. Of these the most important for the Biota Assessment is salinity. Each of these parameters will be discussed in detail in Chapters III - V.

Because the entire Bay has not been completely surveyed for every potential study species, it was found necessary to deal with an organism's habitat from two perspectives. These concepts are: *known habitat* - where an organism has actually been found to exist, and *potential habitat* - where, judging from life history data and known tolerances to stress, conditions are suitable for the organism's existence.

Minor corrections were occasionally made to standardize known distribution and known habitat. Organisms are sometimes displaced into an area where they would not normally be found (such as a fresh water fish being carried into brackish water by a flood). Literature on the distribution of nekton with

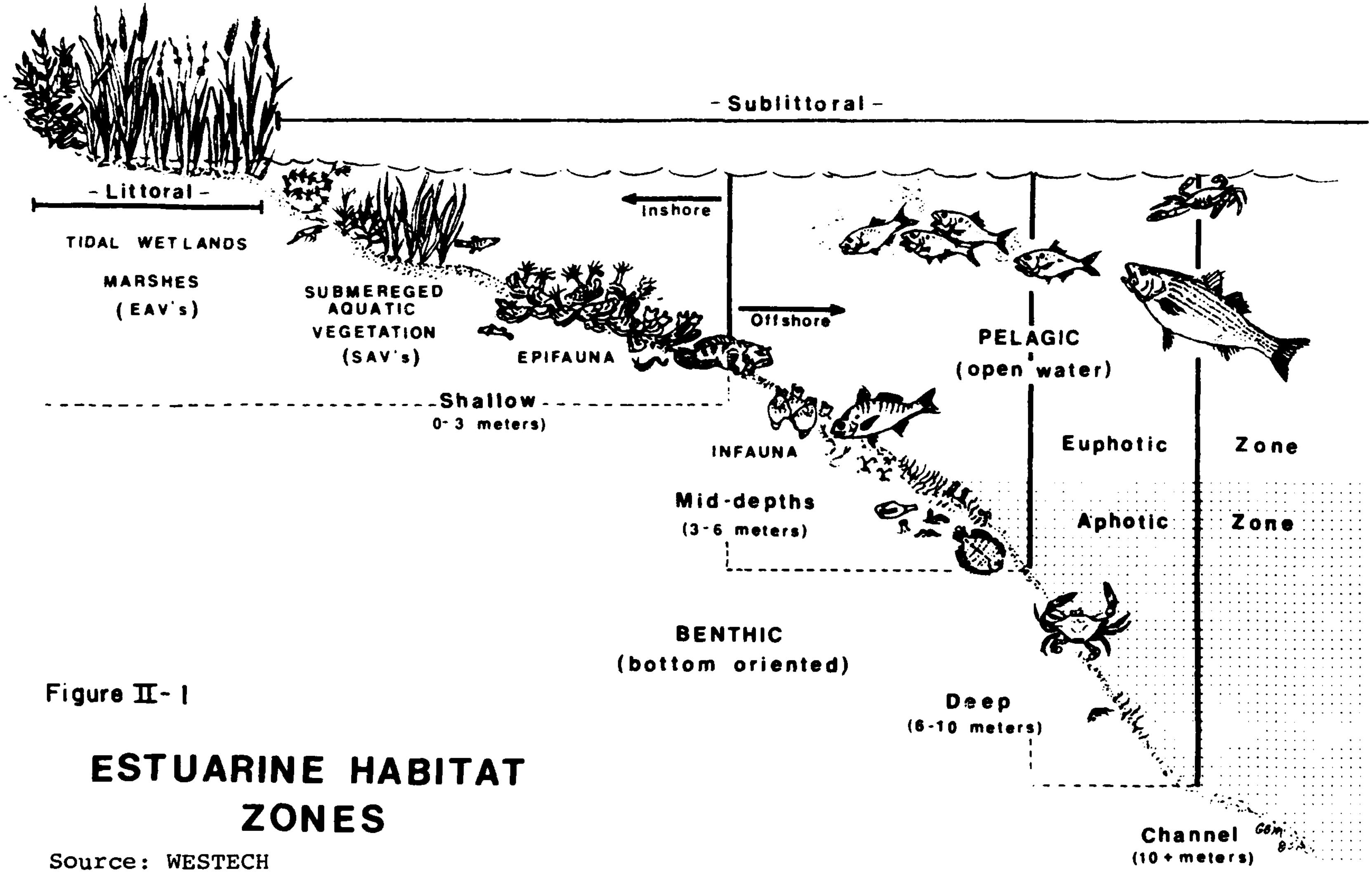


Figure II-1

ESTUARINE HABITAT ZONES

Source: WESTECH

respect to salinity was carefully cross-checked to determine if suspect capture records were outside a species normal range. Definition of habitat for nekton reflects the organism's normal distribution, but not necessarily all recorded catches.

E. SELECTION OF STUDY SPECIES

A systematic screening procedure was developed which insured selection of study species with the minimum of personal bias from either WESTECH staff or reviewers. A sequential screening process was adopted. The screening and selection of study species required consideration of the amount of information available on the life history of the species, its tolerance to physical variables, its linkage to other species in the ecosystem and its human importance, both recreationally and commercially. The screening process was done in a series of stages shown in Figure II-2.

There is no complete catalogue of species found in Chesapeake Bay; however, some 2650 species are thought to exist. The most extensive species compilation is Wass et al. (1972), which does not include "minor groups" (some of which are ecologically important) such as the rotifers.

From the immense universe of Bay species, a list of 167 candidate study species was selected by assessing from the literature, the relative vulnerability of any portion of the species life history to habitat alteration, and other criteria (see Section V.E.). These were then reviewed by the anchor team and Corps Steering Committee. A second screening reduced the list to 81 species, based on availability of detailed literature on stress tolerance and ecosystem importance. The final screening to 57 species was conducted through use of comparison matrices which compiled the sensitivity of each species or any vulnerable life stage to specific habitat alterations (i.e. salinity, food, circulation, and substrate).

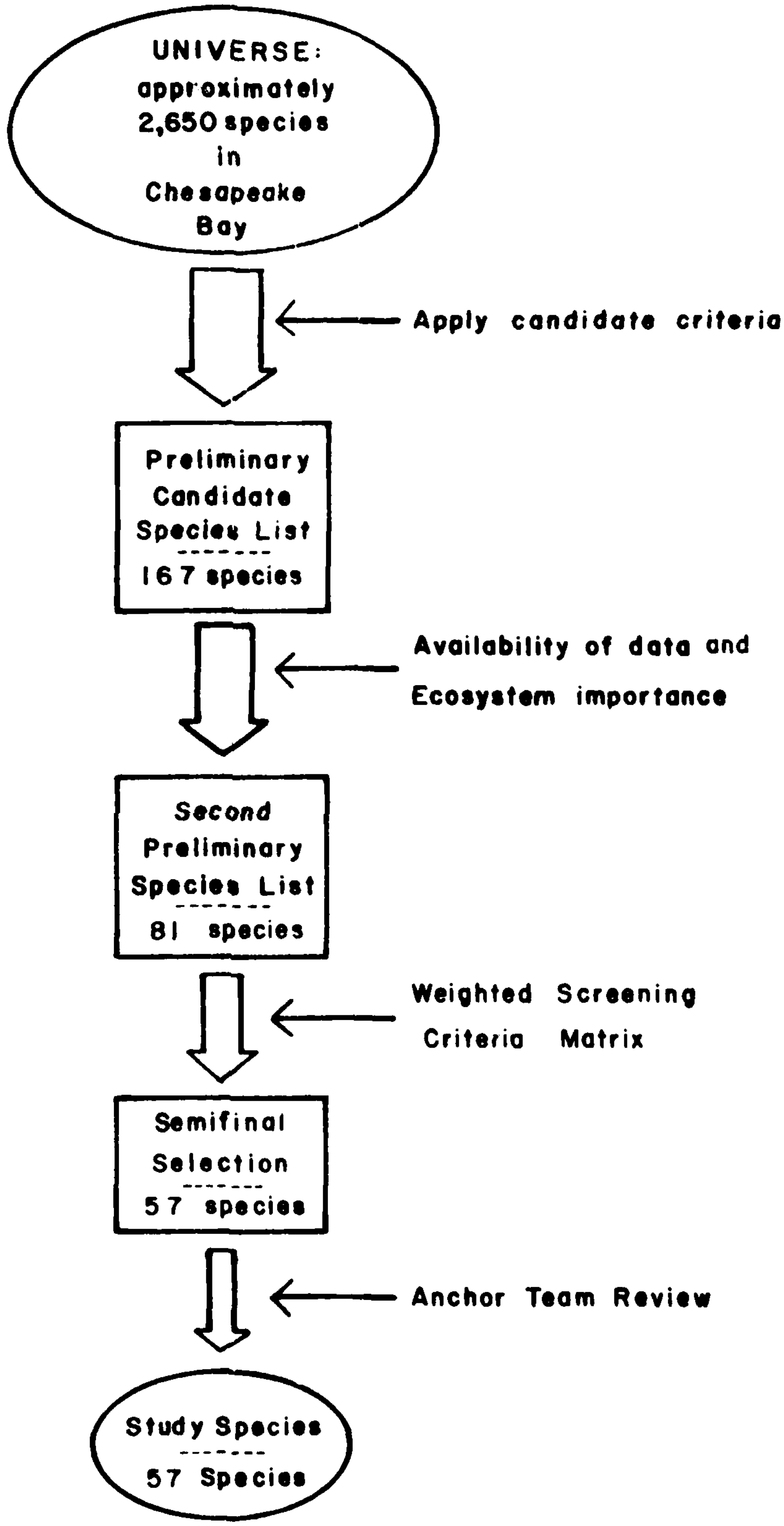


Figure II-2. SCREENING PROCESS FOR SELECTION OF STUDY SPECIES

The amount and quality of available data, the economic or social value and the competative and predatory or trophic relationships were compiled from available literature and discussions with researchers. A weighted ranking system was then employed to identify the most important, most sensitive and most studied of the study species. The weighting scale and selection categories are described in greater detail in Chapter V.

The final selection step was the submission of the study species nominations to the Anchor Team for review. The same list of study species nominations was presented at the second WESTECH seminar for peer reaction and criticism. The final study species list reflects comments received from reviewers. Distributions of these study species form the basis of the map appendix and aided in determining the structure of the Chesapeake Bay Ecosystem Model.

F. DEVELOPMENT OF THE CHESAPEAKE BAY ASSESSMENT METHODOLOGY

Ecological relationships in the Chesapeake Bay estuary were first elucidated by a conceptual model, composed of interrelated organisms which act as functional groups within the model. Usually represented in diagrammatic form, the conceptual model stresses factors of ecological importance, including trophic relationships, respiration, import, export, decomposition, photosynthesis, etc. Other conceptual models of Chesapeake Bay were analyzed and the strengths and weaknesses of each noted (Schofield and Krutchoff 1973, Ulanowicz and Nelson 1974, Green 1978, Stevenson and Confer 1978 (Chap. 5), Ulanowicz et al 1978).

Physical data were examined to determine consistency of format with the data to be produced by the Corps of Engineers Chesapeake Bay Hydraulic Model. Historical salinity information was examined to develop a picture of the range of displacement of salinity zones resulting from variations of inflow (Stroup and Lynn 1963, Lippson 1973, Borman 1974, EPA STORET, NODC Station Archives and many other individual studies). From these and other sources, the conceptual model was developed to contain those elements germane to the biota assessment. The model functionally defines the most ecologically important species. The conceptual model is discussed in detail in Chapter VI.

From this point, a data collection matrix was devised to systematize the extraction of necessary biomass, respiration and feeding data. Where information from the Chesapeake Bay was not available, missing information was sought from other areas. Initial state values, transfer coefficients, temperature and light functions were developed from the data matrix work sheets.

A set of coupled linear differential equations was generated, coded into FORTRAN and entered on the Univac 1108 computer terminal. Debugging involved checking for both coding errors and the behavior of the differential equations in the vicinity of singular points. The functional computerized mathematical model generated by this procedure (named CBEM) was then run for the span of one year in a single geographical sector of the [illegible] system. (See Chapter VI for a full description of Bay segmentation and modeling details). The fluctuations in species biomass over the course of the year's run was then compared with actual data from that Bay segment to determine goodness of fit. During calibration, adjustments were made in respiration or transfer rates where this could be justified by collateral physiological or theoretical studies. Adjustments were preceded by vigorous discussion and an intensive search through the literature for supporting material.

The calibrated CBEM was then tested for validity against independent data. This was followed by testing under altered salinity conditions. These conditons represented a hypothetical change of the magnitude anticipated to occur in the drought scenario. The sensitivity of the CBEM to salinity changes and the validation of the model are discussed in detail in Chapter VI. Figure II-3 displays graphically the interrelations of the subtasks involved in the development of the Chesapeake Bay Ecosystem Model, including the necessary parallel paths of historical data analysis for calibration and validation of the model.

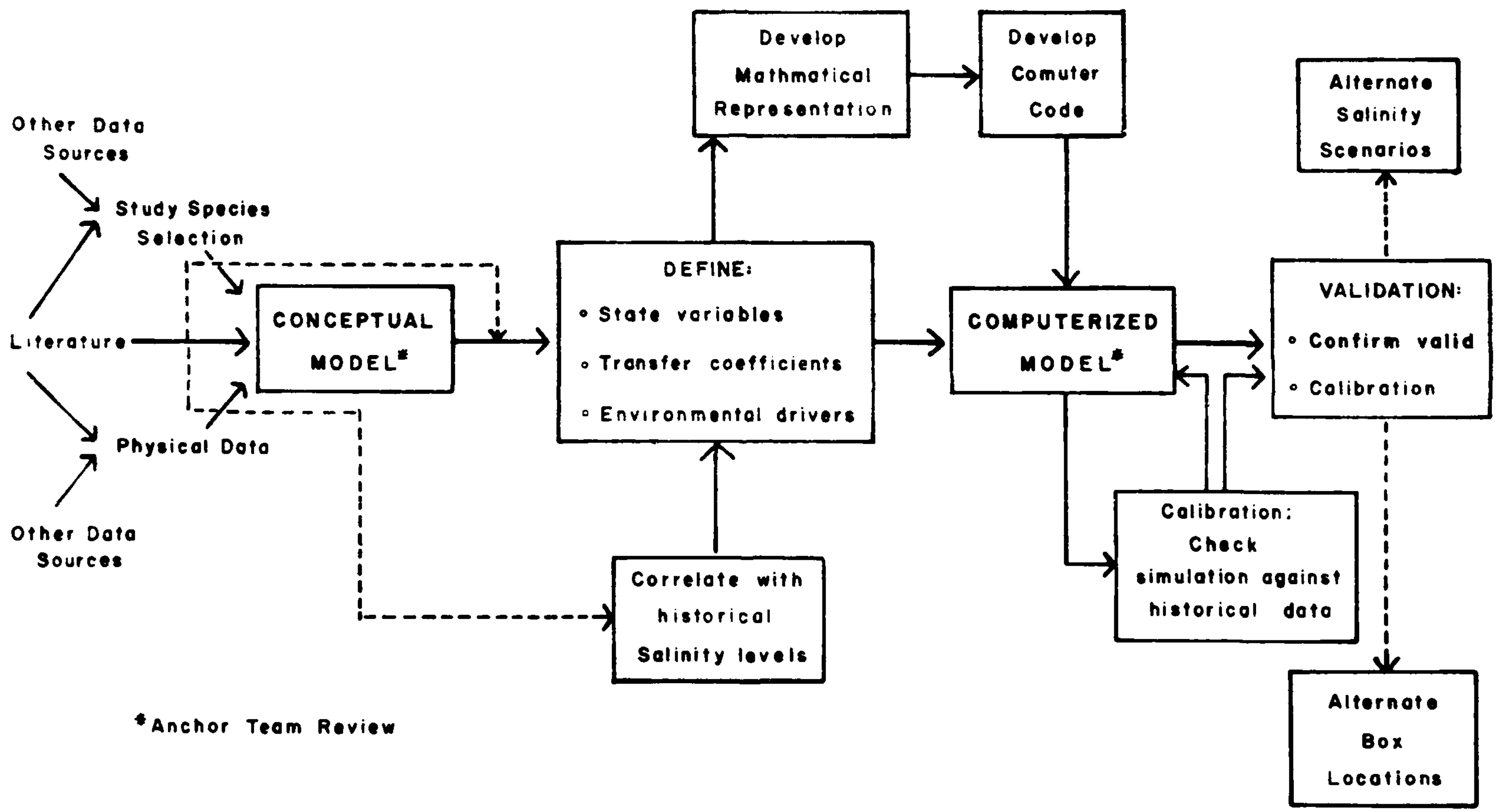
Ideally, the model should be validated on data which were not used to develop it. This effort was only partially successful, however, due to a pronounced scarcity of replicated studies. Anchor team review of the model occurred at the points of the development of the conceptual model diagram and the completion of the functional computerized-mathematical model.

G. MAPPING OF ORGANISM DISTRIBUTION

The distribution of each of the 57 selected study species was mapped on mylar at a scale of 1:250,000. Few species have previously been mapped on a Bay-wide basis, yet the interrelationships of the physical structure of the estuary with the biota stand out most clearly when seen from this perspective. Therefore, a decision was made to map each species on a single sheet showing the entire Bay.

Maps were prepared using shading films and ink or tape lines indicating differing zones or distributional patterns. In many cases, an ecological understanding of distribution entailed considerations of factors such as seasonality, spawning or nursery areas of specialized lifecycle stages. These have been mapped whenever data permit.

The maps have been compiled into an oversized (~33" x 54") map atlas, complete with indices and keys, which is to be on-file at the Corps of Engineers Baltimore District. This document may also be placed on-file at other reference libraries; however, distribution is not known at the time of this writing.



*Anchor Team Review

Figure II-3. APPROACH TO CONCEPTUAL AND COMPUTERIZED MATHEMATICAL MODELING

Reduced example maps, similar in content (but not in total detail) to those in the map atlas are presented in Chapter V. Information pertaining to tolerance of these organisms to salinity and other stresses and factors leading to their selection are included in Appendix B of this report which is intended as a supplement to the Map Atlas.

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III. OVERVIEW OF CHESAPEAKE BAY LITERATURE

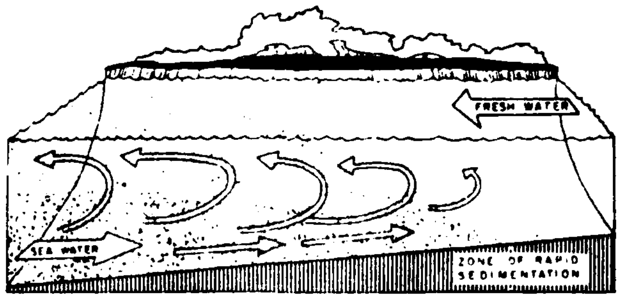
The literature on physical, chemical and biological aspects of the Chesapeake Bay is voluminous. The Chesapeake Bay Bibliography alone (Virginia Institute of Marine Science (VIMS) 1972, 1975, 1976) contains in excess of 10,000 titles. The purpose of this chapter is to acquaint the reader with an overview of the state-of-the-art in these areas. This is by no means a complete summary of the articles reviewed for the Biota Assessment, but is rather intended to lay a framework for the more detailed discussions in Chapters IV-VI.

A. PHYSICAL ASPECTS

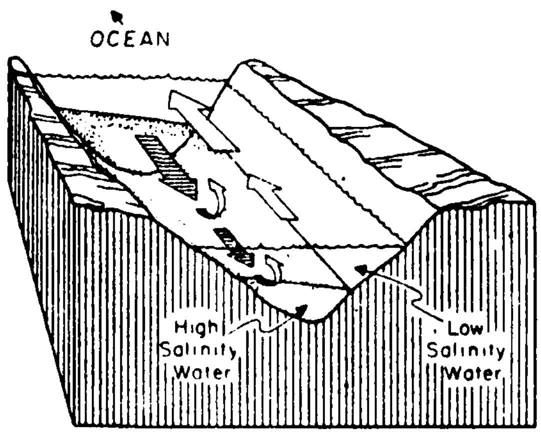
1. Circulation and salinity

An estuary has been defined as a "semi-enclosed body of water that has a free connection with the open sea and within which sea water is measurably diluted with fresh water from land drainage" (Pritchard 1967). The estuary is a dynamic system where inputs from ocean and fresh water sources force complex circulation patterns, as yet incompletely understood.

Pritchard (1953, 1956) characterizes the Chesapeake Bay and its major tributaries as moderately stratified estuaries (his Type B) (Figure III-1). Density differences influence the circulation of such estuaries. The primary factor influencing density is salinity, although temperature exerts seasonal effects (Pritchard 1976) and pressure is also a facotr. Salt water enters the estuary from the ocean, and being denser, flows in under the outward-flowing riverine fresh water. Tidal forces in a moderately stratified estuary are by definition, usually large enough to produce turbulent mixing of salt water into the overlying fresh layers (Figure III-2). Seaward, the salinity of top and bottom layers increases, with the lower layers normally remaining more saline. In the water column the region of most rapid salinity change with depth is termed the halocline. Loss of a volume of salt water to the seaward flowing



A. Side view



B View looking seaward in northern hemisphere

Figure III-1 VIEWS OF A PARTIALLY MIXED TYPE B ESTUARY

Source: Schubel and Pritchard, 1972

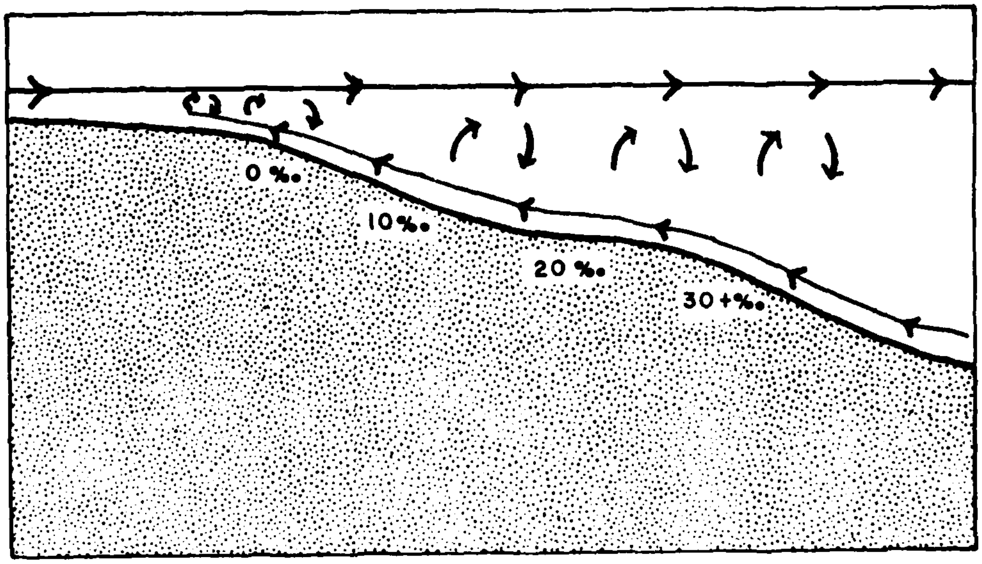


Figure III-2 CONCEPTUAL CROSS-SECTION OF TWO-LAYERED FLOW PATTERN TYPICAL OF THE CHESAPEAKE BAY

Source: Cronin and Mansueti, 1971.

fresh layers along the interface between fresh and salt water is compensated by inflow of saline water at depth (Pritchard 1967).

The result is a net non-tidal circulation pattern that is characteristically two-layered, at least in the Bay mainstem and major tributaries. This pattern is superimposed on the daily tidal oscillations (Figure III-3). In the upper parts of the column, the ebb current exceeds that of the flood, while below this the flood current is greater. The level of "no net motion" (above which the flow is downbay, below which it is upbay) ranges from 3 to 7 meters, depending on the depth of the water column (Pritchard 1976).

Within the Chesapeake Bay mainstem and larger tributaries, the isohalines are displaced by the action of the earth's rotation on currents flowing north or south (Coriolis effect). Thus more saline water is displaced to the eastern shore and fresher water to the western shore of the Bay (Figure III-4) although discharge differences are also a factor. Similarly, the level of no net motion is displaced, being deeper on the western side of the Bay (Pritchard 1952, 1967, 1976). Salinity distribution due to Coriolis effect has the effect of extending the range of a salinity limited species along one shore further north (or south) than the same latitude on the opposite shore. This displacement is also observed in the wider portions of the major western shore rivers. One example of this is the extreme northern limit of Peprillis triacanthus which is reported to be Rock Hall on the eastern shore, and Annapolis on the western shore (Hildebrand and Schroeder 1928).

In the Chesapeake Bay, the major source of freshwater is the Susquehanna River, which accounts for 52% of the total (and 85% of the freshwater entering the Bay above Annapolis)(Boicourt 1969, Schubel 1972). The transition from river to estuary takes place at a prograde front, the surface of this front usually forming a slanted plane with denser salt water along the bottom (Boicourt 1969, Schubel 1972) (Figure III-1).

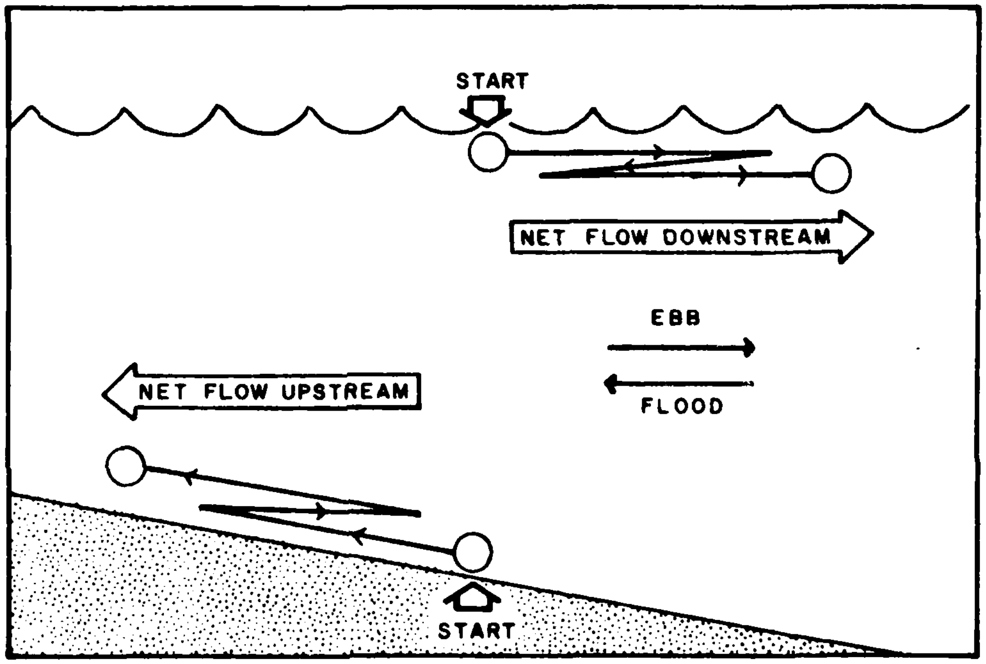


Figure III-3 NET DISPLACEMENT OF WATER IN TWO LAYERED ESTUARINE FLOW

Source: Cronin and Mansueti, 1971.

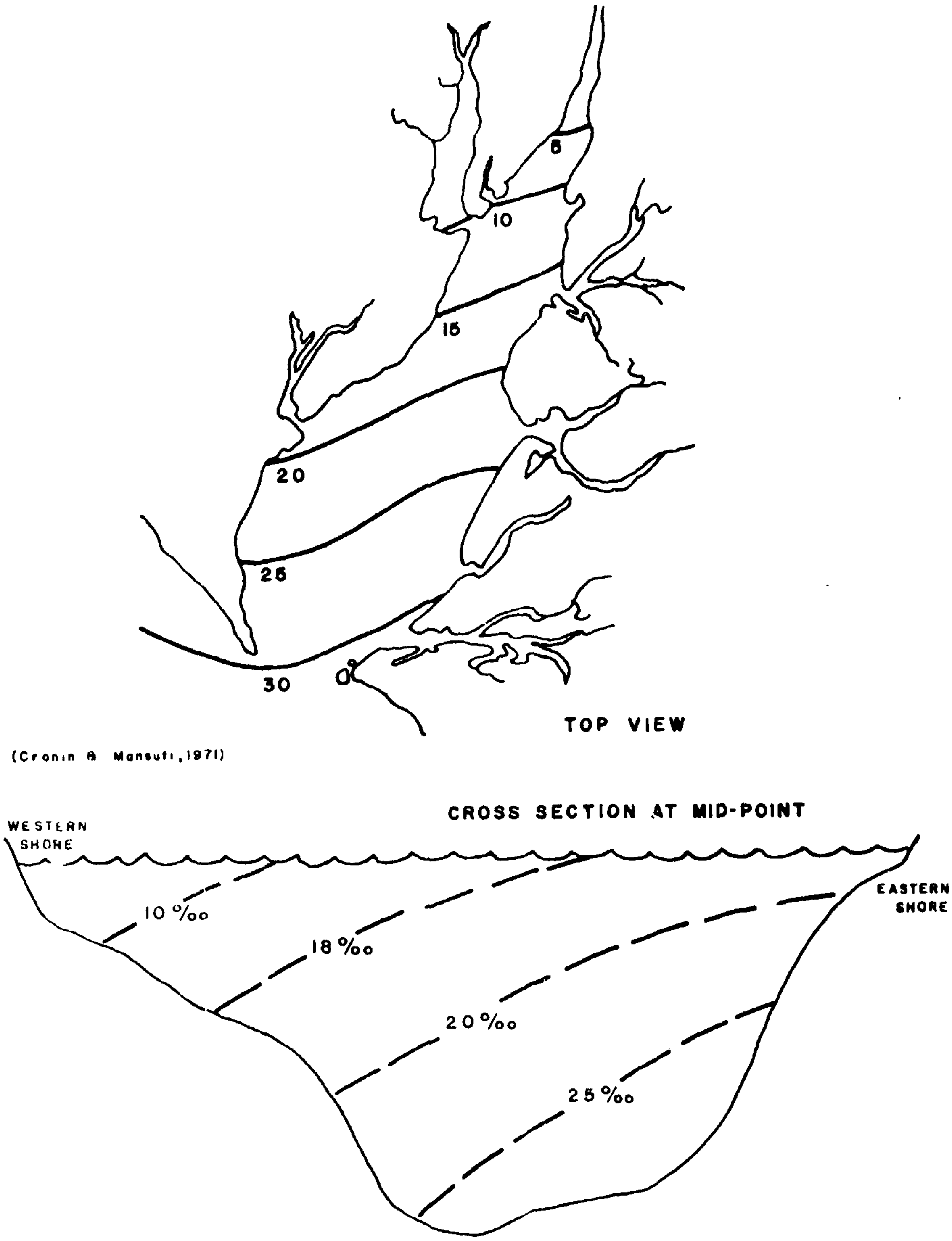


Figure III-4. SCHEMATIC ESTUARY SHOWING CORIOLIS FORCE ON SLOPE OF ISOHALINES IN HORIZONTAL AND VERTICAL PLANES

The horizontal salinity gradient is strongest here, with changes typically an order of magnitude greater than in the main estuarine portion of the Bay (Elliot et al. 1978). Gradients of up to 6‰ in 5km have been observed in spring (Boicourt 1969). The location of such fronts move up and downstream in response to river flow (Boicourt 1969, Seitz 1971, Elliot et al. 1978). Upstream of the front the flow of the entire water column is seaward, downstream the two-layered circulation pattern exists.

Position of this front determines the location of the turbidity maximum, where fine particles from fluvial input or local resuspension (by wind and tidal action) settle into the lower layers, and are carried back upstream (Schubel 1968, 1972). There thus exists a "trap" for both deposition and suspension of sediment in the fresh water/estuarine transition region of Chesapeake Bay and its major tributaries.

The area near the front is highly productive, and represents the nursery grounds for many of the estuarine dependent fish species including those which spawn in the ocean (Wallace 1940, Haven 1957, Muncy 1962, Joseph et al. 1964, Hedgpeth 1966, Reintjes and Pacheco 1976, Talbot 1966, McHugh 1967, Dovel and Edmunds 1971, Harrison et al. 1974, Wiley et al. 1978, Kendall and Watford 1979, etc. Reduction in flow, which would shift this zone upstream, could "compress" the spawning and nursery areas for many fish, such as the striped bass (Polgar et al. 1976). Further upstream from the fresh/salt water interface, changes in inflow in the upper portions of the tributaries can be expected to produce changes in substrate scouring and deposition, water temperature, dissolved oxygen and the depth of water over spawning beds (Whitney 1961, Copeland 1966, Carlson 1968, and Carter 1971). Sedimentation pattern changes are particularly important in shallow areas.

Circulation of the smaller tributaries often does not follow the classic two-layered pattern. They have small drainage areas and relatively little freshwater runoff, and their water is primarily of Bay origin. Variations in salinity of the Bay proper provide the driving forces for the circulation patterns and flushing rates of these tributaries (Schubel 1972, Pritchard 1976). In general, salinity changes in the tributaries lag behind those of the Bay mainstem. Cronin (1966) and Pritchard (1968) noted that seasonal freshets of the Susquehanna are important in flushing small upper Bay tributaries. Thus, controlling Susquehanna flow to the extent that the river's seasonal variation is modified could intensify pollution problems in these areas. Similarly, flushing of Baltimore Harbor only by tidal action would require about 100 days. However, because of main-stem salinity variations, and the vertical salinity distribution in the harbor versus the Bay, a three-layered circulation pattern exists which flushes the Harbor in about ten days (Boicourt personal communication, Pritchard 1976).

Increased volume of river flow has the effect of displacing isohalines downstream, particularly in upper layers, and increasing their angle with the vertical. Stratification is increased and mixing between layers is reduced. This increased outflow at the surface is the driving force for an increased rate of inflow of bottom salty water (Pritchard 1967, Tyler and Seliger 1978). Low freshwater inflow, on the other hand, is characterized by more vertical isohalines, and potentially increased mixing between top and bottom layers. Figure III-5 shows a longitudinal profile (representing Venice System boundaries) towards the head of the Bay (from Seitz 1971). The downstream edge of the zone marks the position of the isohaline during conditions of average fresh water inflow and the upstream edge of the zone is the position of the same isohaline during conditions of low fresh water inflow.

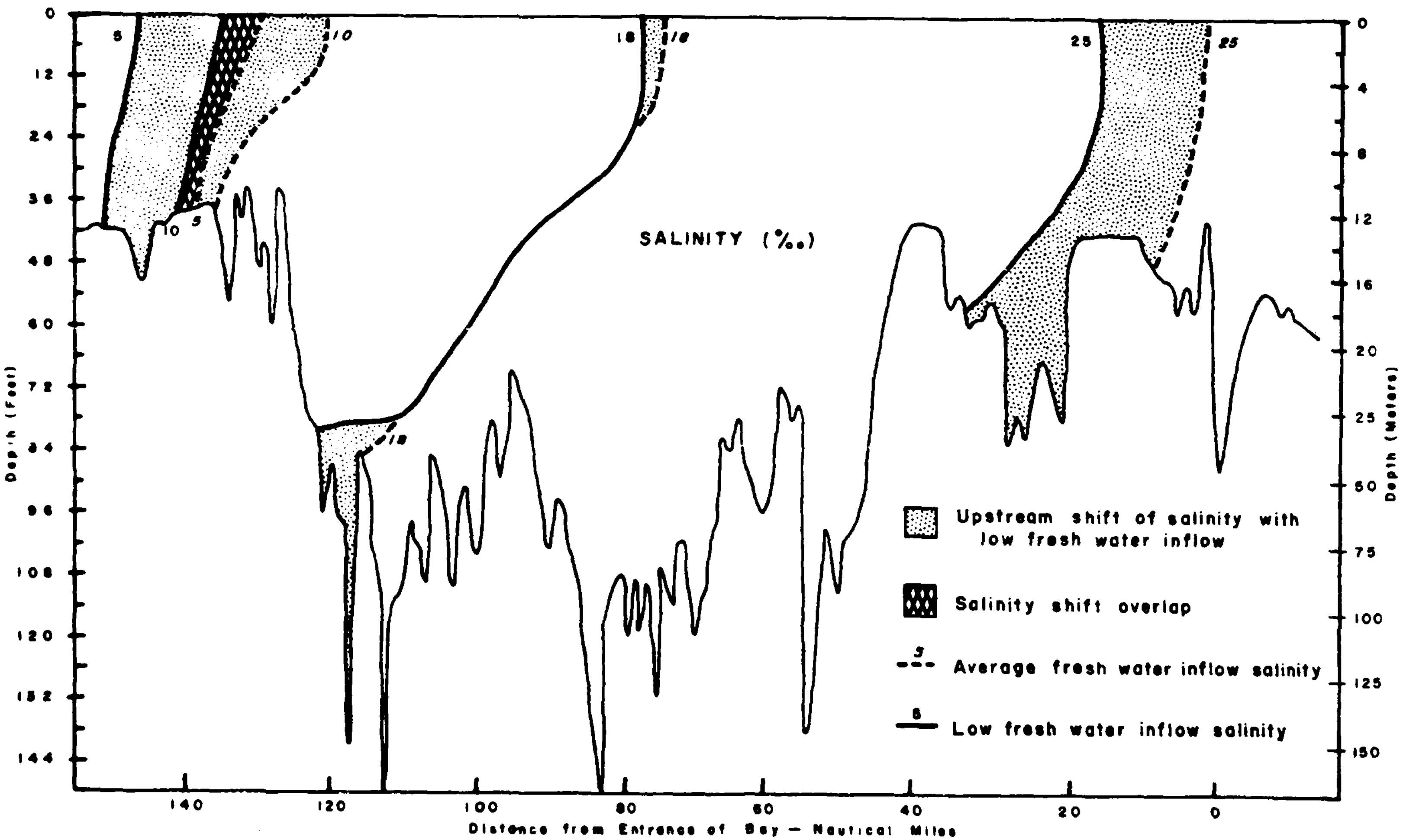


Figure III- 5 LONGITUDINAL SALINITY PROFILES ALONG AN AXIS OF THE CHESAPEAKE BAY DEMONSTRATING THE SHIFT FROM A PERIOD OF AVERAGE FRESH WATER INFLOW TO A PERIOD OF LOW FRESH WATER INFLOW. (From: Seitz, 1971).

Seasonal differences in both salinity distribution and circulation exist in the Bay. This reflects both seasonal changes in river runoff, temperature, and meteorological conditions. In general, density stratification is weakest in winter, partially becuase the deep layers may be warmer than overlying fresher water (Pritchard 1976, Tyler and Seliger 1978). Increased runoff in early spring causes the development of a sharp pycnocline (area of rapidly increasing denisty), and mixing between the two layers is reduced. This increased outflow results in greater inflow of salty bottom water. Increased insolation in summer months maintains the density stratification, although decreased river runoff reduces the rate of saline influx into the estuary. Surface cooling and wind mixing in late autumn weakens stratification throughout the Chesapeake Bay, eventually restoring the winter conditions (Pritchard 1967, Tyler and Seliger 1978).

Meteorological events can also affect estuarine salinity and circulation. It has been often shown that short-term changes can be induced by wind forcing or barometric changes (Elliott 1976, Elliot and Hendrix 1976, Elliot *et al.* 1978). In the Potomac subestuary, for example, Elliot (1976) found the classic two-layered flow occurred 43% of the time, a reverse flow (surface inflow, outflow at depth) about 20% of the time.

Tidal influences have recently been shown to affect vertical salinity distribution on a short-term basis; in the York and Rappahannock Rivers periodic oscillation of stratified and homogeneous conditions corresponded closely to the spring-neap tideal cycle (Haas 1977). In the York river, the amount of freshwater inflow was found to be of secondary importance in mediating the hydrographic characteristics of the estuary. The phenomena has not been fully demonstrated in the Potomac, possibly becuase of its relatively high fresh water outflow maintaining stratification (Boicourt and Taft, personal communication). Reduction in freshwater due to consumptive loss or drought might allow such periods of increased mixing in this tributary. Webb and D'Elia (1980) have shown this destratification phenomenon to be important in supplying nutrients to upper layers and oxygen to deeper layers, particularly in summer when these areas are depleted in those substances.

The characteristic Chesapeake Bay physical environment influence the distribution of organisms within it. In particular, density stratification and two-layered circulation have the following effects:

- formation of a "nutrient trap",
- use by various organisms of the upstream movement of water at depth to enter the estuary and to maintain themselves within it,
- formation of areas of sharp density changes ("fronts") which accumulate nutrients, and are important in the maintenance of plankton blooms.

Nutrient input into the estuary occurs from river runoff, man's activities, and regeneration and remineralization from sediments or within lower layers (Schubel 1972). The remineralized inorganic nutrients are transported back into the upper layers through advective mixing (Redfield 1955, Ketchum 1967, Taft and Taylor 1976). Upstream movement of enriched bottom layers tend to retain the nutrients within the estuary (Odum 1970). However, it should be noted that the same mechanism which allows an estuary to retain and recycle nutrients also can cause it to concentrate pollutants.

Many organisms utilize the upstream flow at depth to transport themselves into and within the estuary. The larvae and young of ocean-spawning fish use this means to reach their nursery grounds in low salinity areas of the rivers; such species include menhaden, croaker, spot, weakfish, red and black drum, and the American eel (Haven 1957, Mansueti 1960, Norcross 1967, Thomas and Smith 1973). Many invertebrate larvae also depend upon estuarine circulation to remain within the Bay (Copeland 1966, Wood and Hargis 1971, and Sandifer 1973, 1975). For example, blue crab zoea are released in the water column at the Bay mouth, where surface currents tend to carry them out of the estuary. After metamorphosis into megalopes, the larvae descend and are returned to the estuary in bottom-flowing deep water (Van Engel 1958, Sandifer 1973, 1975, Provenzano personal communication). Some species have evolved behavior patterns which take advantage of maximum up-estuary flow during flood tide to reach adult habitats upstream; among these are oysters and blue crabs (Cronin and Mansueti 1971, Wood and Hargis 1971). Planktonic organisms obviously are dependent upon the Bay's circulation to control their distribution. Zooplankton may migrate to deeper layers to avoid being carried out of the estuary (Cronin et al. 1962). The importance of two-layered flow to the transport of phytoplankton has been well demonstrated in Chesapeake Bay (Tyler and Seliger 1978) (see Section III-C).

Fronts (meeting or convergence areas of water masses of differing density or flow direction) serve to concentrate not only nutrients and non-living particulate material, but also planktonic organisms (Ryther 1955, Seliger et al. 1979, Tyler and Seliger 1980). Reduction in river outflow will weaken such convergence zones, with implications for nutrient and plankton distribution (Tyler personal communication).

The moderation or elimination of freshets by flow modification has biological implications beyond the effect on small tributary flushing. Freshets are important in controlling upstream penetration of certain predators, such as the oyster drill (Andrews 1964). They also carry detritus into the estuary from upland or marsh sources; this is important in zooplankton food chains and thus to survival of fish larvae (Heinle and Flemer 1975, Setzler et al. 1979). Freshets may also have adverse effects, such as the loss of blue crab zoea to the continential shelf (Van Engel, personal communication). Regulation of flow to allow timed fresh water releases has been suggested to alleviate some of these problems (Andrews 1964).

2. Light

In addition to salinity, light is a physical factor of importance to the biota of Chesapeake Bay. Light penetration *per se* in the Bay has been studied by Burt (1953, 1955a, 1955b), Schubel (1968), and Champ (1979). In addition, light intensity and extinction was surveyed in numerous investigations of Bay primary productivity (e.g. Whaley *et al*. 1966, Flemer 1970). The general picture of light penetration is related to concentrations of plankton and suspended sediment. From the Susquehanna flats downstream about 6 to 10 nautical miles is the highly turbid zone of the fresh-saltwater interface. Minimum light penetration occurs in this region. From the Bush River south to the entrance to Baltimore Harbor, the water remains turbid and light penetration increases only slightly. From Baltimore Harbor entrance south to the Patuxent, light penetration improves, but decreases again at the mouth of the Patuxent, Potomac and Rappahannock Rivers. Low flow reductions on any of these rivers should result in decrease in sediment loading and increase in water transparency to light.

3. Temperature

Water temperature has been investigated by Beaven (1960), Ritchie and Genys (1975), and Brady (1976), among others. Over twenty years of records taken by the Chesapeake Bay Institute have been presented in graphical form in a series of atlases (Whaley and Hopkins 1952, Stroup and Lynn 1963, Seitz 1971). Ritchie and Genys (1975) summarized 39 years of records taken in the lower Patuxent, and used them to generate an average temperature function (used in the Chesapeake Bay Ecosystem Model, see Chapters II and VI).

In general, Chesapeake Bay water temperature shows marked spatial and seasonal changes during the year. Temporal changes are the most obvious; minimum temperature approach 0°C in January or February, and may reach 30°C in late summer (Schubel 1972). Low flow conditions should have only minimal effects on temperature, except possibly locally in tributaries or near thermal discharges from power plant cooling systems.

4. Data Gaps

Two major gaps in the literature of the physical parameters of Chesapeake Bay have become apparent. There is the absence of synoptic (same slack tide) salinity information for nearly all tributaries. This data gap is not likely to be remedied soon due to the high cost of large scale field sampling. The output from the Chesapeake Bay hydraulic model is the most reasonable potential source for this information. Numerical models developed to date, while promising, are also too expensive to provide the necessary level of detail over the entire Chesapeake estuary.

The second information gap concerns detailed understanding of subsurface water motion on short to medium range time scales (less than one spring-neap tidal cycle). Elliott and Hendrix's (1976) intensive observations on the Potomac circulation have demonstrated the complexity of these sub-surface currents in one small portion of the Chesapeake estuary. Whether the hydraulic model can also provide some of this information remains to be established.

B. CHEMICAL ASPECTS (Nutrients and Related Water Quality Factors)

The nutrients of primary importance in the Chesapeake Bay are nitr[illegible] phosphorus. These two nutrients frequently limit biological growth, especially plant growth. When the input of these nutrients into the water is increased, algal and other plant growth can greatly accelerate, resulting in degradation of water quality. The amount of nutrient loading carried in tributaries varies seasonally and with river flow, although data on these relationships are scarce.

Most of the nitrogen and phosphorus which enters the Chesapeake system is carried in water. Dissolved nutrients and phosphorus-laden particulates enter the Bay in run-off from the land (non-point source) and in the effluent from municipal and industrial waste water treatment plants (point source). Some nutrients, primarily nitrogen, are present in rainwater and small amounts of nutrients are found in atmospheric dust.

Because the amount of nitrogen and phosphorus entering the Bay is highly correlated with river flow, the six major rivers that supply approximately 90% of the fresh water inflow to the Bay are also most significant in nutrient inputs. In terms of fresh water inflow, the Susquehanna supplies 52% of the total; the Potomac, 18%; the James, 14%; the Rappahannock, 4%; the York, 2%; and the Patuxent, approximately 1.5% (VIMS 1975). The Susquehanna River has a profound effect on the nutrient balance of the upper Bay due to its large percentage of the total flow. The annual flow of river water into the Bay from the three dominant rivers is shown in Table III-1.

Annual flows of freshwater into the Bay are subject to great variability, with a concurrent variation in the nutrient loading. Annual flows have varied from greater than 100,000 cubic feet per second (cfs) in 1972 to less than 50,000 cfs in 1965 (Figure I-3). The amount and type of use of the land drained by the river system has a large effect on the rate of run-off and the amount of nitrogen and phosphorus carried into the river (Table III-1). The Susquehanna drains the largest amount of land (27,510 mi^2) followed by the Potomac (14,670 mi^2) and the James (10,102 mi^2) (VIMS 1975). However, the land-use type modifies the run-off pattern of water and nutrients. For instance, a natural ecosystem such as a forested watershed decreases the rate of run-off and the loss of nutrients compared to a clear cut watershed (Likens et al. 1970). Impervious surfaces, such as roads or shopping center parking lots allow no infiltration and the water leaves the land immediately. Some surfaces, such as residential lawns, allow some infiltration.

Point sources of nutrients are primarily from municipal sewage treatment plants although nutrients are also discharged from federal installations and industrial facilities (Brush 1974). Few wastewaters undergo tertiary treatment so that the effluent entering a river is usually high in nitrogen and phosphorus. The constituents of effluent from major treatment plants on the Patuxent River basin are listed in Table III-2. Combined flows

TABLE III-1.

Total Flow and Percentage of Drainage Basin in Selected Land Use Categories by Major Rivers

Land Use Type	Susquehanna[1]*	Patuxent[2]*	Potomac[3]
Cropland	23.9%	36[a] %	40[a] %
Pasture	9.5	--	--
Forest	55.6	41	50[b]
Urban	4.2	16	5
Other	6.8	7	5
MEAN RIVER FLOW[4]	39,200 cfs	637 cfs	14,000 cfs

1. Heinle et al. 1980.
2. Correll 1976.
3. Mihursky and Boynton 1978.
4. U.S.Geological Survey 1979.

a. Agriculture
b. Forest and Brushland

* The Susquehanna & Patuxent are regulated rivers.

from these major plants alone are over 25 mgd (40 cfs) in a river with 637 cfs discharge. The BOD loading is roughly 225 mgd. Thus under normal flow, sewage waste flow comprise 6 percent of the total discharge. This percentage can be expected to increase considerably during low flow conditions.

The nutrient load on a river system can have a great effect on the river itself while the effect on the Bay is of lesser importance. For instance, the effluent entering the Potomac estuary near Washington D.C. has resulted in the upper and middle reaches of the estuary becoming highly eutrophic (Jaworski 1974). The lower reaches of the river are still relatively healthy, however, due (to a large extent) to the distance (183 km) from the source of the nutrient input (VIMS 1975). The upper and middle reaches of the estuary in effect serve as tertiary waste water treatment areas. However, the nutrient concentration combined with the volume of flow of the Potomac make the estuary important in nutrient inputs to the Bay.

Flow also affects downriver nutrient loading. The Patuxent estuary, which has a relatively high nitrogren and phosphorus concentration (Mihursky and Boynton 1978) has a lesser nutrient loading rate to the Chesapeake Bay because of the lower rate of water flow. Although overall loading rates to the Chesapeake Bay depend primarily on total flow; the state of the river system itself depends on the nutrients entering it. Table III-3 shows the amount of waste water entering each major river system from known point sources and the percentage of the total river flow that this represents.

Non-point sources of nutrients become most important under high flow conditions, when rainfall snow-melt carry nutrients from the land. They are less important (contribute less nutrients) under low flow conditons (Clark et al. 1973). Various land use types lose nitrogen and phosphorus at various rates and these rates change seasonally with precipitation and river flow. Table III-4 shows the total area of major land use types in the Chesapeake Bay and the percentage of non-point source nutrient loading attributable to each.

TABLE III-2

Quality of Effluent From the Major Waste Water Treatment Plants in the Patuxent River Basin[a].
(Source: Mihursky and Boynton 1978)

Plant Name	FLOW mgd	BOD mg/l	TKN mg/l as N	NH_3 mg/l as N	NO_2 & NO_3 mg/l as N	Total P mg/l as PO_4
Savage	4.4	27.4	12.9	10.3	1.6	40.6
Parkway	5.4	--	29.2	27.0	0.3	67.9
Maryland City	0.6	--	13.6	9.0	1.6	46.7
Md. House of Corrections	0.7	32.0	14.0	11.0	0.0	12.8
Fort Meade No. 1	2.1	24.0	17.4	13.4	2.5	36.5
Fort Meade No. 2	1.8	1.8	18.2	14.7	0.6	36.6
Patuxent	2.8	30.6	23.4	16.8	0.0	11.3
Bowie	2.5	19.2	33.6	29.0	0.1	33.9
Western Branch	5.4	39.8	13.9	8.5	1.9	25.3
Marlboro	-	--	--	--	-	--

a. Maryland Environmental Service. 1974. Data collected June 5, 1973. Data were obtained from 24-hour composite sampling.

TABLE III-3

Amount of Waste Water Entering Each Major River System from Point Sources and the Percentage of the Total Flow that this Represents. (Modified from Heinle *et al.* 1980)

River	Point Sources of Sewage (#)	Percent of Freshwater that is Sewage
Susquehanna	557	1.4
Patuxent	41	3.8
Potomac	670	4.8
Rappahannock	-	-
James	302	2.5
York	-	-

TABLE III-4

Major Land Use Types in the Chesapeake Bay and the Seasonal and Total Percent of Non-point Source Nutrient Loading Attributable to Each (Modified from Correll 1976)

Land Use Type	Winter		Spring		Summer		Fall		TOTAL	
	N	P	N	P	N	P	N	P	N	P
Cropland	15	26	29	14	38	29	15	2	28	17
Pasture	15	18	10	8	5	9	30	39	13	12
Forest	11	61	3	0.4	5	3	19	51	7	11
Other	46	--	34	23	18	53	--	--	--	--

N = Nitrogen

P = Phosphorus

The percentages of the nitrogen and phosphorus loading attributable to non-point sources for each of the major river systems are listed in Table III-5. These data demonstrate that non-point sources must be considered when developing nutrient source budgets and the relationships between nutrient loadings and river flow.

Guide and Villa (1972) calculated the nitrogen and phosphorus loading of the Bay from the non-tidal portions of the major tributaries (Figures III-6 & III-7). Three rivers, the Susquehanna, Potomac and James, dominate that nutrient loading rate of the Bay. The Susquehanna, with its great rate of flow, controls the nutrient loading of the upper Chesapeake Bay (Schubel 1972). An estimate of the total annual input of nitrogen and phosphorus to the Bay, with and without the inclusion of the Bay sub-estuaries, is shown in Table III-6. The difference in the two columns represents the nutrients contained in the sub-estuaries, either in suspension or in bottom sediments.

The nitrogen and phosphorus entering the Chesapeake Bay is cycled through the biota, lost to the sediments and atmosphere, and removed from the Bay when living organisms, such as fish, migrate or are caught by fisherman. The amount present in the water at any time reflects a complex and dynamic process. While nitrogen and phosphorus concentrations alone say little about the functioning of the process, they can indicate the presence of nutrients in excess of the amount needed by the biota at that time. The chemical form the nutrient takes, such as ammonia or nitrate, can also indicate the immediate source. In general, nitrogen concentrations in the Bay decrease from north to south (Whaley et al. 1966, Carpenter et al. 1969, Taylor and Grant 1977), while concentrations in the river systems depend upon land use and point-sources of nutrients. Nutrient concentrations are generally higher in the Patuxent, Potomac, and James Rivers, and lower in the Susquehanna, Rappahannock, and York Rivers.

C. BIOLOGICAL ASPECTS

The biological aspects of Chesapeake Bay are the primary concern of the Biota Assessment. Here, the major groups of Bay organisms

TABLE III-5.

Percentage of Nitrogen and Phosphorus Loading Attributable to Non-Point Sources for Each Major River System (modified from Heinle et al. 1980)

River	Nitrogen	Phosphorus
Susquehanna	74 - 78	--*
Patuxent	39	9
Potomac	77 - 85	--
Rappahannock	81	--
York	93	72
James	51	--

* No data

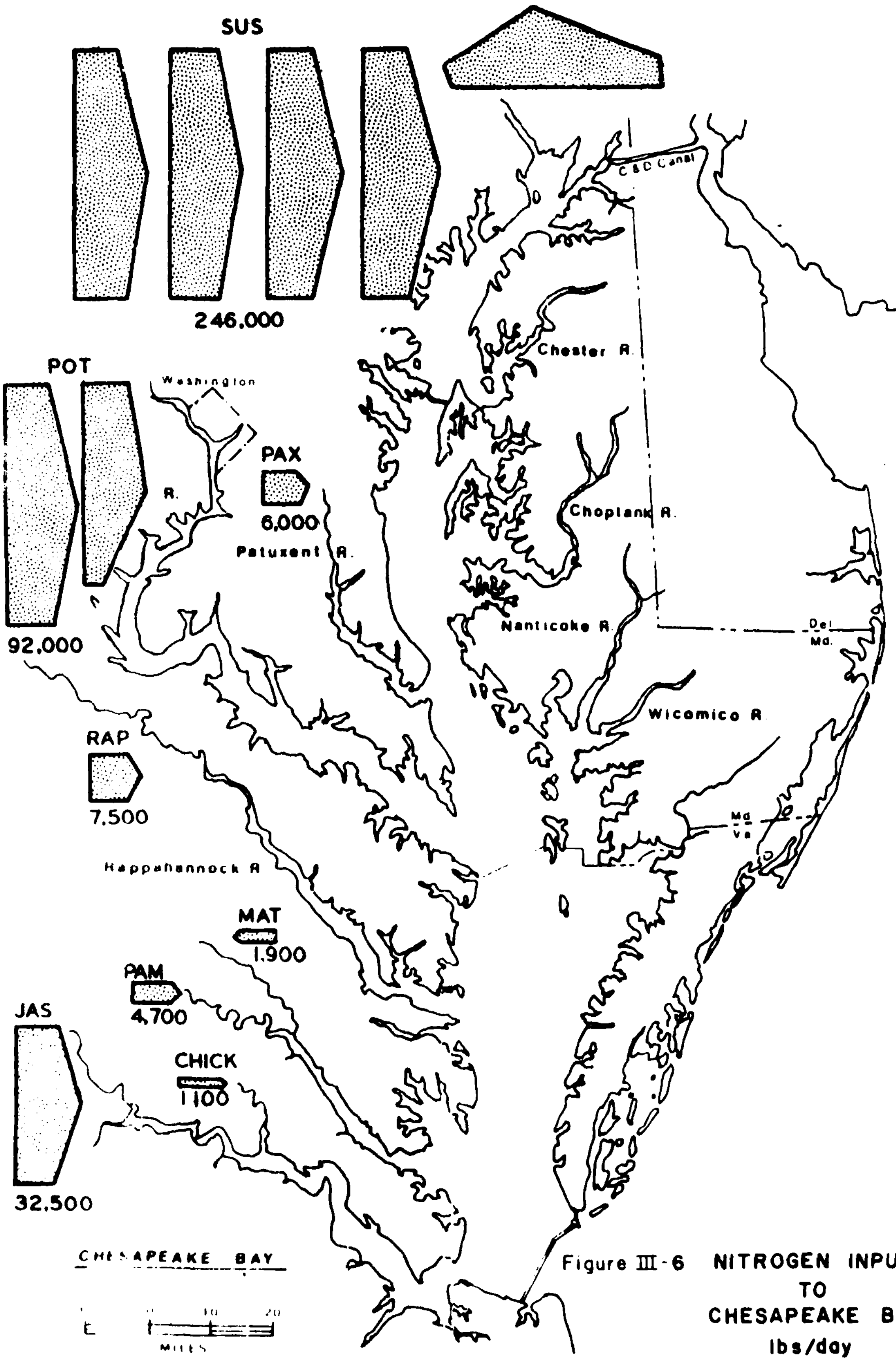


Figure III-6 NITROGEN INPUT TO CHESAPEAKE BAY lbs/day

Source: Guide & Villa, 1972

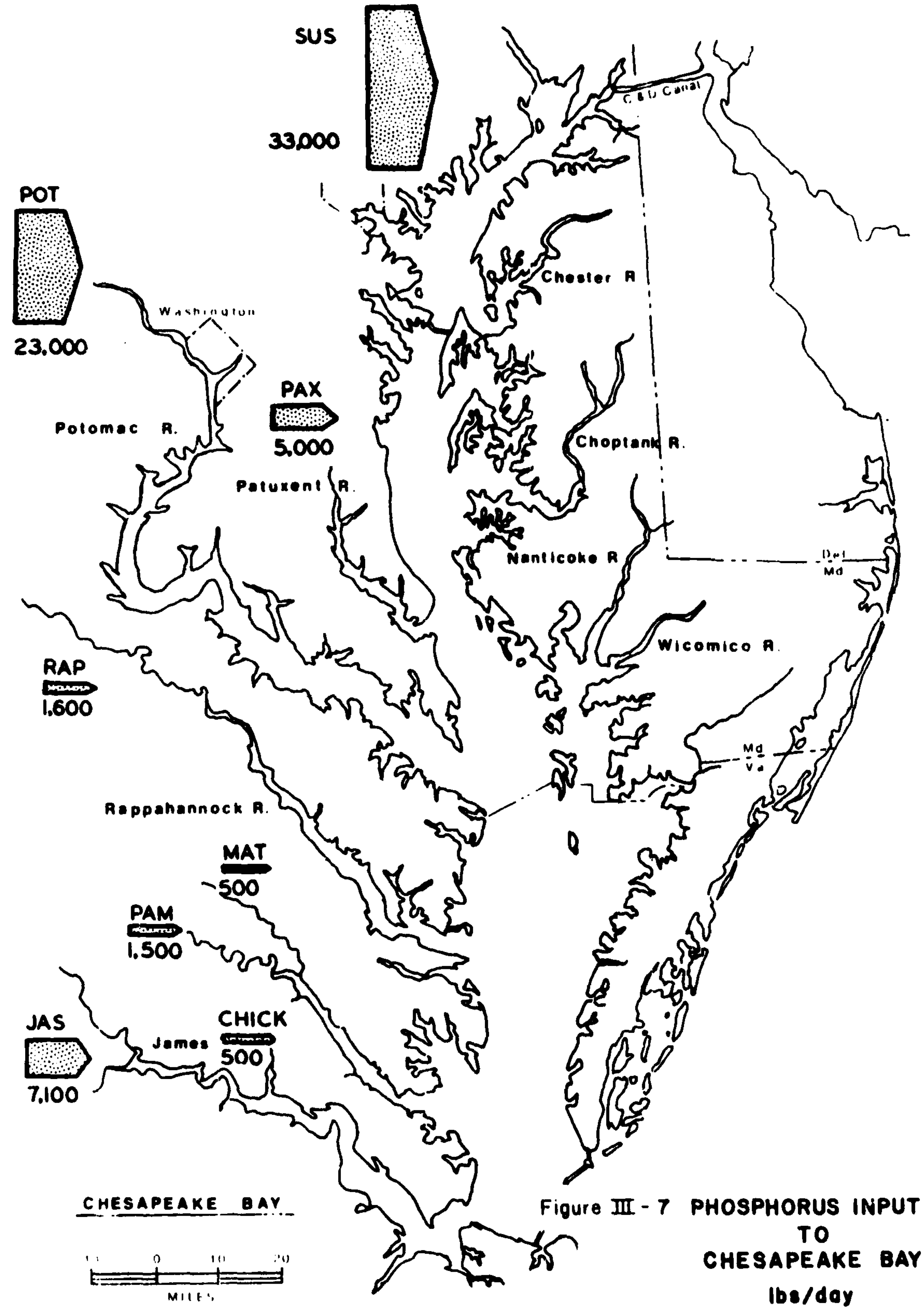


Figure III - 7 PHOSPHORUS INPUT TO CHESAPEAKE BAY lbs/day

Source: Guide & Villa, 1972

TABLE III-6.

Annual Input Budget for Nitrogen and Phosphorus in the Chesapeake Bay (Source: Jaworski 1980 in Heinle et al. 1980)

Source	Phosphorus (kg/day)	Nitrogen (kg/day)
Entire Chesapeake Bay Including Sub-estuaries		
Municipal/Industrial	28,700	87,700
Upper Basin Land Runoff	10,200	195,400
Air	2,500	14,800
TOTAL	41,400	297,900
Chesapeake Bay Proper Excluding Sub-estuaries		
Municipal/Industrial	16,900	45,900
Upper Basin Land Runoff	5,200	131,500
Air	1,400	8,200
TOTAL	23,500	185,600

are individually presented in a brief sketch of the general literature. Literature relevant to the modeling of interactions between organisms is presented in Chapter VI.

1. Phytoplankton

Phytoplankton represent the major primary producers in the Chesapeake Bay, and are a key link in estuarine food webs. For this reason, studies of phytoplankton ecology, systematics, and productivity are common in the Chesapeake Bay literature. In general, such investigations fall into two categories: those dealing with species composition, distribution, and seasonality, and the factors influencing them; and those studies dealing with seasonal and spatial variations in primary productivity, nutrients, and nutrient-phytoplankton inter-relationships.

The earliest studies were qualitative in nature. The first survey of note was that of Wolfe and Cunningham (1926). It was concerned primarily with species composition, distribution, and seasonality. Two major periods of abundance were identified, spring and fall. Cowles(1930) used Wolfe and Cunningham's collections and generally agreed with their conclusions regarding phytoplankton distribution in space and time. Observations of two years of seasonal plankton variations at the mouth of the Patuxent River, Maryland, were summarized by Morse (1947). She related phytoplankton occurrence to the four hydrographic seasons of Chesapeake Bay: autumn, winter, spring, and summer. Morse recognized autumnal and vernal maxima of diatoms and a summer-early fall maximum of dinoflagellates. Griffith's (1961) guide to Chesapeake Bay phytoplankton provided a synopsis of knowledge then current on the distribution and seasonality of major species in Chesapeake Bay.

More intensive sampling of phytoplankton communities began in the 1960's and continues to the present. Patten, Mulford, and Waumier (1963) identified four periods of population maxima and six peaks of species diversity in the lower Bay. The "spring bloom" was most pronounced in the York River and decreased in intensity proceeding outward to the Bay mouth. Diatom species w. prominent in winter and flagellates during warm periods. The flora was most abundant and diverse in western stations. The significance of nannoplankton (small forms passing through the usual phytoplankton nets) was noted in this study and others of the period. Marshall (1966) found certain nannoplankters to be the most numerous species, particularly at certain mid-Bay stations.

Whaley and Taylor (1968) surveyed the phytoplankton along the Bay mainstem using pumped samples to reduce patchiness. In general, the same dominant net phytoplankters were found as were cited by Cowles(1930). Mackiernan (1968) recorded 118 species of dinoflagellates from the polyhaline zone of the York River. The winter flora was dominated by neutitic, stenohaline marine species, while summer was characterized by numerous "red water" blooms in the river and adjoining Bay mainstem. The annual cycle of net phytoplankton in the mesohaline Calvert Cliffs area showed highest biomass in November and February, but lowest diversity at this time (Mulford 1972). (Collection and preservation procedures used in this study may have caused a loss of the flagellate species usually dominant in summer.) Nannoplankton were found to account for a major part of phytoplankton biomass by McCarthy et al. (1974) and Van Valkenburg and Flemer (1974). The latter paper also identified dominant species and recorded their seasonality, apparently the first systematic survey of this important fraction of the Chesapeake Bay flora.

Loftus et al. (1972) found an increase in importance of large dinoflagellates relative to nannoplankton following a pulse of rainfall (and dissolved nutrients) from several small western tributaries of the Bay. As run-off decreased and vertical mixing increased, the species composition changed, with nannoplankton eventually regaining dominance. Zubkoff and Warinner (1975) and Seliger et al. (1975) recorded the incidence of dinoflagellate blooms in the lower and upper Chesapeake Bay respectively. Seliger and his co-workers correlated the appearance of these blooms to conversion of inorganic nutrients to organic forms, predation on nannoplankton by rotifers and tintinnids, and the positive phototaxis of the dinoflagellates reducing the effects of flushing rates.

An important paper by Tyler and Seliger (1978) related the annual transport of a red-tide dinoflagellate, Prorocentrum mariaelebourae, from its wintering area near the Bay mouth, to its bloom area in the upper Bay (Figure III-8). The organism is carried in the upstream flow of saline water at depth and thus serves as a model for the similar transport of larvae fish, crabs, etc. to their upstream nursery grounds. Entrainment of the dinoflagellate into the subsurface layers occurs at convergence zones along frontal regions associated with high streamflow in southern Chesapeake Bay tributaries (Seliger et al. 1979, Tyler and Seliger 1979).

Phytoplankton biomass (as measured by chlorophyll a concentration) and productivity has been surveyed in Chesapeake Bay for over 30 years. In 1949 - 1959 the Chesapeake Bay Institute sampled for chlorophyll a as well as nutrients and turbidity in the Bay mainstem and selected tributaries (Stroup and Wood 1966). In general, phytoplankton biomass was highest in the spring months, moderately high thru the summer, and with a brief peak in early fall. The spring bloom was most obvious in the lower Bay.

Whaley et al. (1966) surveyed the upper Chesapeake Bay and some tributary rivers during the low flow years of 1964 - 1966; these data are summarized by Carpenter et al. (1969). In general, chlorophyll values were highest in the upper Bay in late summer and summer values in the upper Potomac were up to an order of magnitude greater than those in the main Bay.

Taylor and Hughes (1967) investigated upper Bay productivity during the summer of 1964, a period of drought conditions. Average primany production was highest in August and October at all stations (274 and 216 mg $Cm^{-2}M^{-1}$ respectively). Production in the tribu-

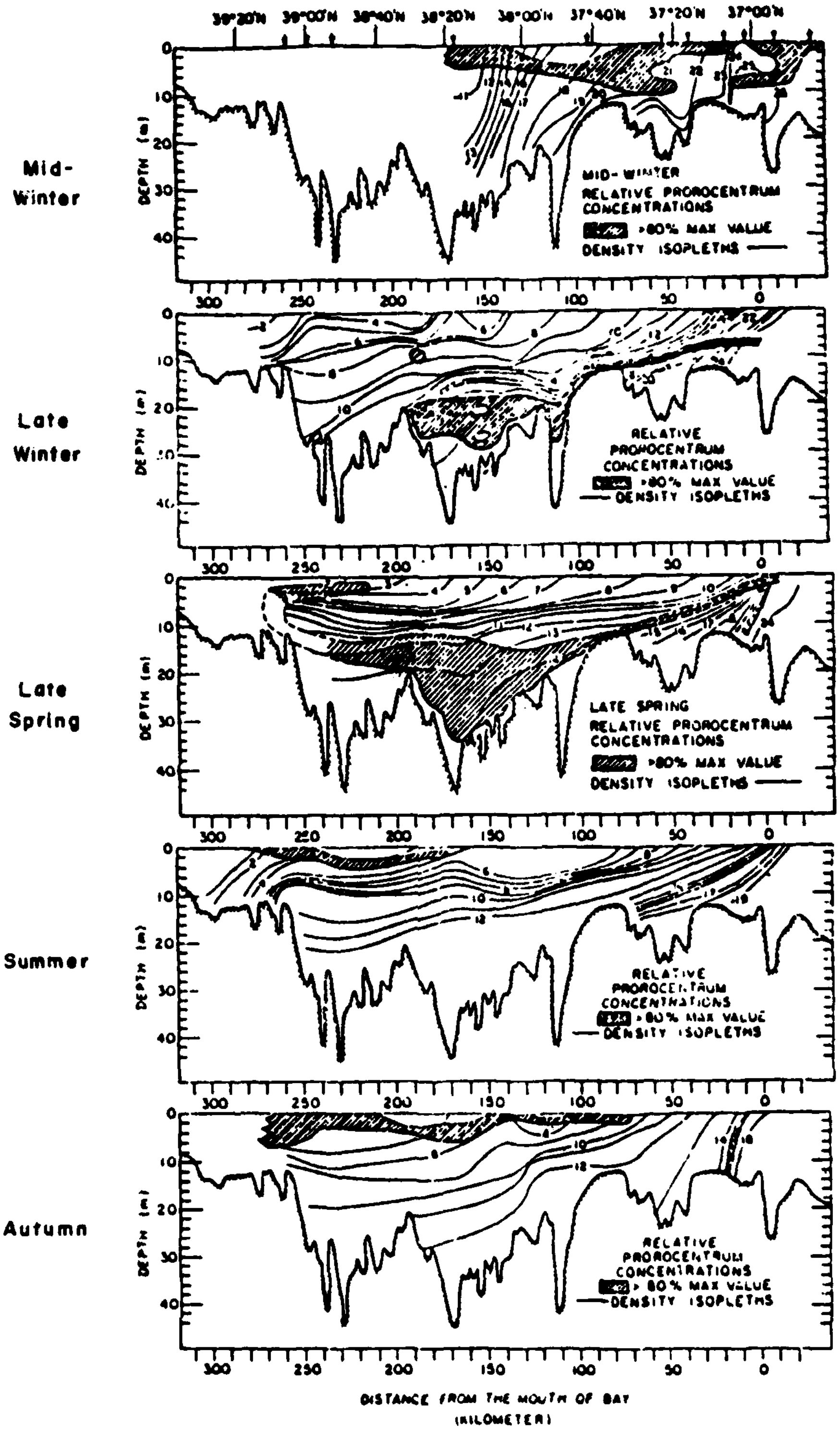


Figure III-8 **SUBSURFACE TRANSPORT OF *Prorocentrum* OVER AN ANNUAL CYCLE, 1975**

Along Longitudinal Sections of Chesapeake Bay

(From: Tyler & Seliger, 1978)

taries (Chester, Magothy, Miles, Severn and South Rivers) was generally less than the main Bay during this period.

Flemer (1970) estimated annual primary production and standing crops in the northern half of Chesapeake Bay. Both parameters were maximum during the warmer seasons, particularly in the oligohaline zone. Values were lower in the mid-Bay stations and less variable seasonally. Also, the upper stations tended to have a single warm season peak, rather than the spring/fall peaks observed in more saline portions of the Bay.

In the Patuxent River, Stross and Stottlemyer (1965) found that upstream stations were about 3 times more productive on basis of volume, but had a shallower euphotic zone. Production increased in all areas of the estuary during the low flow years 1963 and 1964, relative to 1962 (Table III-7). As productivity appears to be light-limited in the upper river, decreased turbidity due to low runoff could account for some of these observed changes. Cory (1974) analyzed productivity information from 1963 to 1969 in the same tributary and observed a doubling gross primary production in this period. He attributed this to increased nutrient loading and predicted occurrence in anerobic conditions of the Bay's major tributaries, such as the Potomac (Carpenter _et al_. 1969, Jaworski _et al_. 1972, 1974) and James (Brehmer and Haltiwanger 1966), as well as the upper Bay (Clark _et al_. 1973). The increase in nutrient input has generally resulted in an increased phytoplankton biomass (but not always - see Heinle _et al_. 1980) and changes in phytoplankton species composition (Clark _et al_. 1973).

Nannoplankton, which represent a significant fraction of phytoplankton biomass, also accounts for much of the Bay's primary production. McCarthy _et al_. (1974) found these small forms to constitute 80% of the measured chlorophyll _a_ and over 85% of the productivity during a two-year survey of the Bay mainstem. There appeared to be no particular seasonal trend in the importance of the smaller forms.

TABLE III-7.

Production of plant material (as grams dry weight per m^{2*}) in three areas of the Patuxent River Estuary. (From Stross and Stottlemeyer 1965)

Period	Area: River mouth to Benedict	Benedict to Truman Pt.	Truman Pt. to Milltown Landing
July - Dec. 1962	270.8	181.2	224.4
Jan. - June 1963	234.0	124.8	91.8
July - Dec. 1963	366.4	329.8	180.4
Jan. - June 1964	423.2	333.8	273.0
Annual Average	647.2	484.8	384.8
Rate/day	1.8	1.3	1.1

*Computed dry weight as 2 times weight of carbon content.

Van Valkenburg and Flemer (1974) had similar results for the relative productivity of nannoplankton (in this case, only forms less than 10 μm diameter). Some seasonal differences were observed, however, with nannoplankton least abundant during October, November and December.

Autoradiography was used to estimate the rate of uptake of the phytoplankton in the Rhode River sub-estuary; the phytoplankton fraction smaller than 10μm was metabolically most active (Faust and Correll 1977). In the estuary, 70 to 80% of primary production and nutrient uptake from June to November was due to dinoflagellates and to other small forms in Feburary. Friebele et al. (1978), based on work in the Rhode River, showed that the phosphate uptake rate was a function of the surface to volume ratio of the cell, thus giving a competitive advantage to smaller phytoplankton.

Nutrient availability and quality also mediates the abundance and distribution of phytoplankton. Much work has been done in the last decade to elucidate phytoplankton nutrient dynamics, primarily for the major elements of nitrogen and phosphorus. Correll (1975), using autoradiography, found that 1) bacteria, and 2) nanoplankton are the major consumers of dissolved orthophosphate. He postulated an estuarine phosphorus cycle in which dominant pathways lay between bacteria, suspended and bottom sediments, through zooplankton, to organic dissolved forms, and again to dissolved inorganic phosphate.

Taft and Taylor (1976) found maxima of soluble reactive phosphate in deep water in late summer. This was concurrent with the seasonal maxima of surface phytoplankton production and surface particulate phosphate and the summer hypoxia in deep layers. The suggestion was made that, at this season, phosphate that is produced by bacterial remineralization at or near the bottom fails to be precipitated as an isoluble ferric salt due to anoxic conditions. The nutrient is eventually transported into the euphotic zone, where it is rapidly utilized by the phytoplankton.

McCarthy et al. (1977) found distribution and abundance of four nitrogenous nutrients (NO_3-, NO_2-, NH_4+, and urea) to be variable both seasonally and spatially along a Bay transect from south of Baltimore to the continental shelf. Phytoplankton utilized urea and NH_4^+ preferentially over nitrate or nitrite. When the sum of reduced N was too little to meet phytoplankton needs, nitrite was used. When nitrogen in all forms was in undersupply, each of the four compounds was used at rates proportional to their availability.

Recently, Loftus et al. (1979) have found that in eutrophic systems, inorganic carbon can be the limiting nutrient. In such areas, species with an ability to utilize bicarbonate ion directly, rathern than free CO_2, have a competitive advantage.

In general, then, low flow conditions may affect phytoplankton either directly, by altering composition and range of the various associations or indirectly, through effects on nutrient input, estuarine flushing rates, turbidity, and circulation. These and other factors might be expected in influece productivity as well.

2. Zooplankton

Zooplankton represent the important primary consumers in most estuarine food webs and thus are a key link in the transfer of phytoplankton production to higher trophic levels. Other significant components of the zooplankton are carnivorous forms such as ctenophores and the planktonic larvae of invertebrates and fish.

As with phytoplankton, earliest zooplankton studies were generally qualitative surveys of species composition and distribution (e.g. Wilson 1932, Davis 1944). The latter author noted the characteristic seasonality of the Bay's zooplankton and its domination in most areas by calanoid copepods. In the upper Bay and upper reaches of the tributaries, the zooplankton composition is greatly influenced by input from tidal fresh water areas (Goodwyn 1970, Sage et al. 1976), while intrusion of typical marine species often occurs in the lower Bay (Burrell 1972, Grant and Olney 1979). Diversity is typically lowest in the oligohaline and low mesohaline areas.

Herman *et al*. (1968) surveyed the seasonality and distribution of zooplankton in the Patuxent River (during a low flow period). Copepods comprised 98% of total zooplankton excluding ctenophores and cnidaria. *Eurytemora affinis* dominated upriver in low salinities, while *Acartia tonsa* was most abundant downstream except during March and April, when it was replaced by *A. clausii*. Cladocera and meroplankton were less important. Goodwyn (1970) summarized results of a two-year survey of the Bay mainstem from the Elk River to the Patuxent. He found species composition to remain roughly similar from 20 ‰ down to 5 ‰, to change sharply at 5 ‰, and to remain similar thereafter down to 0 ‰. Salinities above 5 ‰ were usually dominated by *Acartia tonsa* or *clausi*, *Oithona colcava*, *Podon polyphemoides*, and the rotifer *Synchaete*. Below 5 ‰ dominants included *Eurytemora*, *Bosmina longirostus*, and *Brachionis calicyflorus*.

Highest concentrations were found in spring and summer, and at mid-Bay. He hypothesized that the larger standing crops of zooplankton in 1968, relative to those in 1967, may be related to the lower Bay mouth where marine cladocerans such as *Evadne* or *Penillia* occasionally predominated. *Acartia clausii* was much more numerous relative to *tonsa* than in the upper Bay region and persisted longer into the spring season. This reflects the preference of that species for higher salinities, observed by workers in other areas (e.g. Jefferies 1962).

As discussed above, copepods are often the dominant members of the Bay zooplankton community, both in numbers and biomass. One species, *Acartia tonsa*, may account for 95% or more of copepod numbers in mesohaline areas (Jacobs 1978, Lippson *et al*. 1979). Heinle (1960) found this species to be most abundant during seven months of the year in the Patuxent River; production during the summer was estimated to be about 2.6 mg $m^{-3} hr^{-1}$. At least half the phytoplankton production was consumed by this species summer months.

Production of this species was over an order of magnitude smaller in the Rhode River estuary. In this area, Allen et al. (1976) suggested that rotifers account for the bulk of summer zooplankton production.

Eurytemora affinis, an abundant copepod in the oligohaline zone, is important to the feeding and survival of many juvenile fishes, including herring (Berrbridge 1972) and striped bass (Setzler et al. 1979). In spring months the carbon demand of this species may not be met by phytoplankton production and the difference is apparently made up by consumption of detritus (Heinle and Flemer 1975) (Figure III-9). This has implications applicable to low flow conditions, since detrital input occurs in late winter or early spring from ice scoured marshes or upland sources (Biggs and Flemer 1972, Heinle et al. 1977) and is related to fresh water discharge. For instance, production of copepods in the Patuxent was four times less in 1966 (a low flow year) than in 1979 (an average flow year) (Mihursky and Boynton 1978). Such changes may be of significant importance to other estuarine organisms. A minimum density of copepods appears necessary for successful metamorphosis and survival of striped bass larvae (Setzler et al. 1979 Beaven and Mihursky 1980)(see Table III-8).

Ctenophores, particularly the ubiquitous Mnemiopsis leidyi, and cnidarians, especially the sea nettle, Chrysaora quinquecirrha, exert heavy predatory pressure on smaller zooplankton. Burrell (1972) observed that copepods were virtually eliminated within an area of the York River occupied by high densities of Mnemiopsis. A freshet in 1969 which dispersed the ctenophore allowed copepod numbers to rebound (Figure III-10). Predation on Mnemiopsis by the ctenophore Beroe ovata can be severe, particularly in late summer and fall. Elimination of Mnemiopsis by Beroe can also enhance the abundance of copepods and other zooplankton (Burrell and Van Engel 1976). Chrysaora is also known to prey on zooplankton as well as upon Mnemiopsis (Miller 1979, Cargo and Schultz 1967).

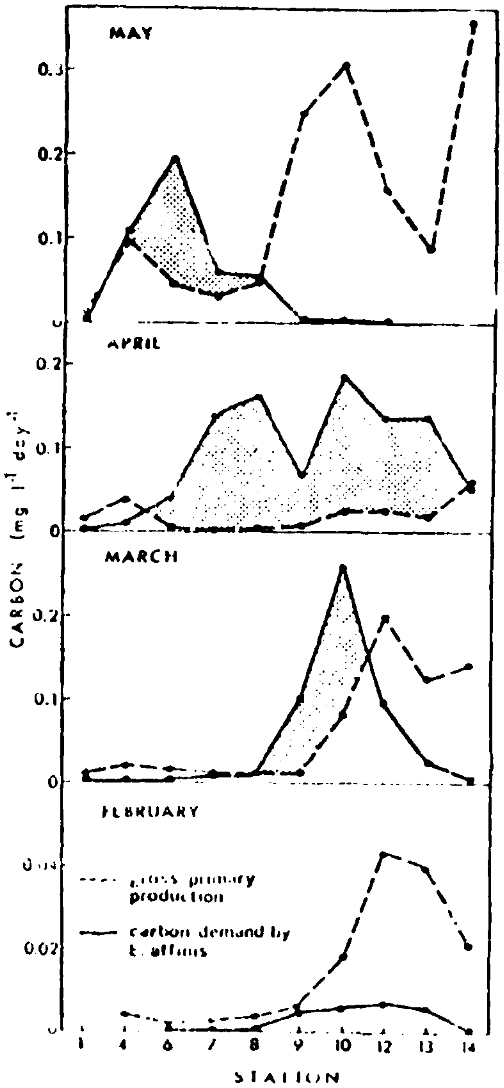


Figure III- 9 CARBON DEMAND OF *Eurytemora affinis*
IN RELATION TO GROSS PHYTOPLANKTON PRIMARY PRODUCTION
per m^3

Shaded areas represent carbon demand not met by algal production

(From Heinle and Flemer, 1975)

TABLE III-8

Stomach Contents of Each Larval Stage Expressed as Percentage of Larvae Containing Food Item.

Source: Beaven & Mihursky 1980

Food Item	Yolk sac larvae	Finfold larvae	Post-finfold larvae
Copepoda	55.4	72.7	84.6
E. affinis	11.2	24.2	72.3
E. affinis copepodites	4.4	4.0	0
E. affinis adult or copepodite	3.2	4.0	5.8
Cyclopoid adults	4.8	11.1	21.2
Cyclopoid copepodites	13.7	11.1	5.8
Cyclopoid adult or copepodite	10.0	11.1	5.8
Unidentified copepods	30.5	38.4	44.2
Unidentified nauplii	1.2	0	0
Acartia tonsa adult	0.4	0	0
Cladocera	39.4	49.5	76.9
Bosmina longirostris	36.9	50.5	65.4
Daphnia species	2.8	4.0	26.9
Chydorus species	0.4	0	1.9
Unidentified cladocerans	0.8	1.0	1.9
Rotifera	58.6	34.3	13.5
Brachionus calyciflorus	42.6	16.2	9.6
Brachionus species	8.6	7.1	0
Unidentified rotifers	6.8	1.0	1.9
Rotifer eggs	53.8	30.3	9.6
Keratella species	2.4	0	0
Tintinnidae	0.8	0	0
Unidentified crustaceans	0.8	0	0
Unid. invertebrate material	5.2	6.1	1.9
Unidentified material	21.7	10.1	5.8
Total no. of larvae examined	439	110	56
No. of empty larvae	190	11	4
Percentage empty	43.3	10.0	7.1

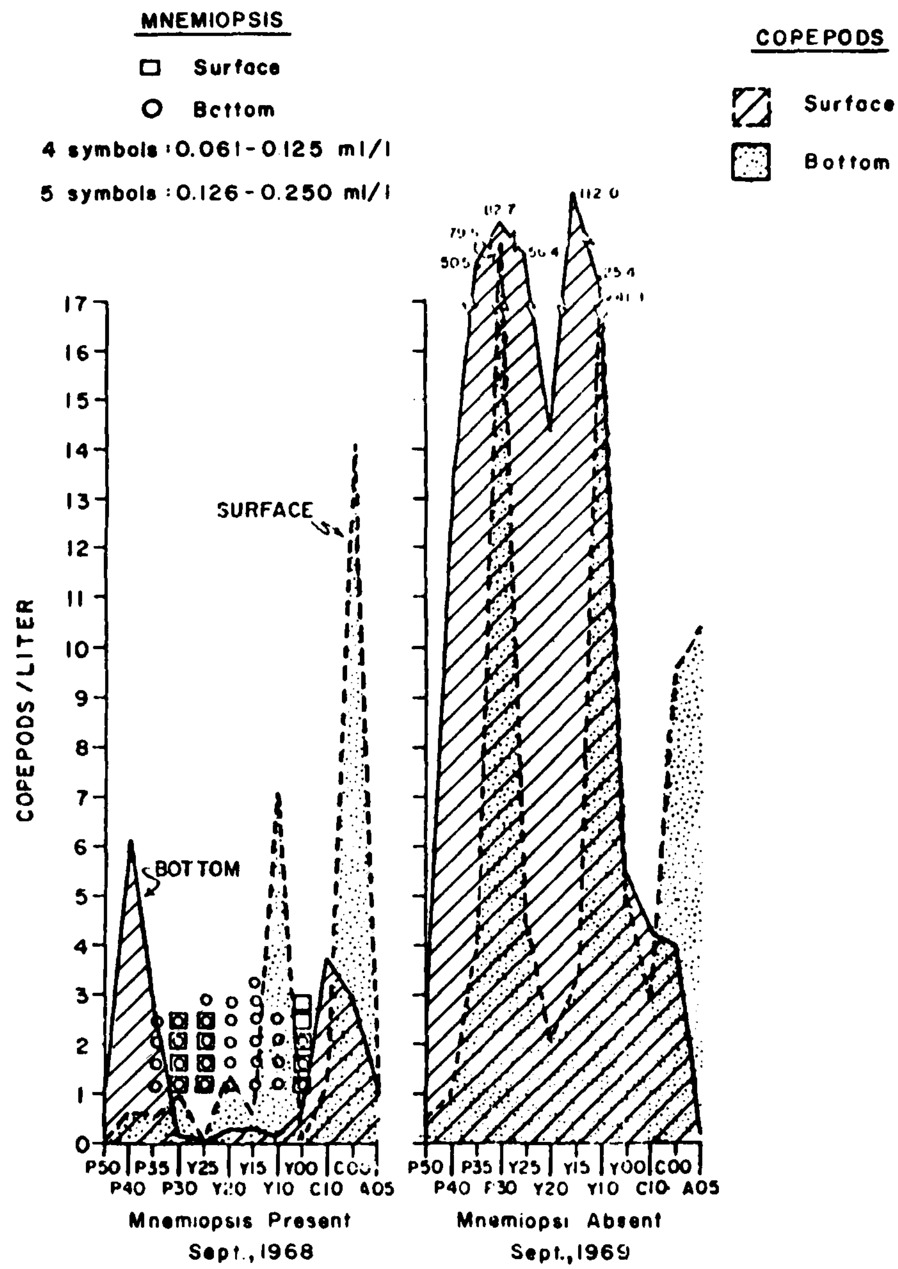


Figure III-10 **EFFECT OF MNEMIOPSIS ON THE ABUNDANCE OF COPEPODS**

Abundance Sampled Along A Bay-York River Transect
September, 1968 compared to September, 1969

Source: Burrell, 1972

A suprising gap in the literature was the paucity of information on abundance, feeding rates, and related factors for these important predators in most areas of the Bay. Bishop (1967) estimated that the average density of ctenophores in the Patuxent during summer months could consume 31% of the standing crop of Acartia daily. A similar figure was derived by Clifford and Cargo (1978) from feeding experiments of Chrysaora upon Artemia nauplii; however, these results may not be applicable to natural conditions. Mihursky and McErlean (1972) reported summer and fall sea nettle densities in the Patuxent River from 1964 through 1967. Biomass values were variable, with a maximum of about 45 ml/m^3. The organism penetrated further upstream in the low flow year of 1964 than it did in 1967. However, in general, knowledge on the functional ecology of these species in Chesapeake Bay is lacking, relative to information on their role in other systems (such as Narragansett Bay).

Again, relatively little is known about the abundance and seasonality of micro-zooplankton such as rotifers, as well as tintinnids and other protozoans. Since these forms feed typically on nannoplankton, are extremely abundant, have rapid metabolic processes and fast turnover rates, they probably contribute greatly to energy flux through the Bay's ecosystem (Loftus et al. 1972, Allan et al. 1976). Rotifers are most numerous in fresh water areas and few species penetrate to brackish or marine reaches (Lippson et al. 1979). They are considered an important source of food for some species of larval fish in oligohaline nursery areas (Beaven and Mihursky 1980). Tintinnids may be tremendously abundant (numbers in excess of 500,000 m^{-3} are not uncommon), but little has been published on their role in Chesapeake Bay. Several ongoing studies should eventually shed light on their distribution and functional ecology (Brownlee, personal communication; Heinbokel, personal communication).

Low freshwater inflow and accompanying salinity changes would be expected to affect both community composition and distribution. Zooplankton predators might penetrate further into the Bay. Indirect effects could also be expected; decreased input of detritus from upriver, change in estuarine flushing rate and alteration of saline inflow at depth. Changes in phytoplankton composition or productivity might produce second-order effects on zooplankton.

3. Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) are found in the fresh, oligohaline, mesohaline and polyhaline waters of the Chesapeake Bay. Maximum depth of SAV in the Bay is approximately three meters (Stevenson and Confer 1978), although in clearer water SAV species occur at greater depths.

Substrate does not seem to be a critical factor for any species in the Bay (Stevenson and Confer 1978) although certain SAV species are commonly found on particular substrates. Approximately 20 species of SAV are found in the Chesapeake Bay, although the frequency of occurrence is species dependent (Table III- 9) with about 12 of the species forming dominant associates in at least one area of the Bay.

Submerged aquatic vegetation is important in the Chesapeake Bay for a number of reasons, the most important probably being habitat modification. Like terrestrial plants, aquatic vegetation serves as a habitat for many species. These species include benthic invertebrates, fish, and even other plant organisms (epiphytes). As an example, Table III-10 lists the dominint infaunal species found by Orth (1973) in *Zostera marina* beds in the Chesapeake Bay area. The maximum number of species and individuals were 62 and 32,913, respectively, in these beds. Orth (1977) showed that significantly more species and infauna were found in the *Zostera* beds than in surrounding substrate (Figure III-11).

Submerged aquatic vegetation can also serve as a substrate for organisms. Marsh (1973) studied the epifaunal of *Zostera* in the York River estuary and found 16~,000 individuals of 100 species in 48 samples of *Zostera* plants (Table III-11). Orth and Boesch (1979) examined beds of *Zostera*, *Ruppia*, and *Zostera*/*Ruppia* for epifaunal abundance and found *Ruppia* to have more than 5000 individuals per gram of grass in April.

TABLE III-9

Submerged Aquatic Vegetation Found in Maryland and Virginia Waters of the Chesapeake Bay.

Callitriche verna

*_Ceratophyllum demersum_

Chara sp.

*_Elodea canadensis_

Elodea nuttallii

*_Myriophyllum spicatum_

*_Najas spp._

*_Nitella sp._

Potamogeton crispis

Potamogeton filiformis

Potamogeton foliosus

Potamogeton nodosus

*_Potamogeton pectinatus_

*_Potamogeton perfoliatus_

*_Ruppia maritima_

*_Vallisneria americana_

*_Zannichellia palustris_

*_Zostera marina_

* Dominant in the Chesapeake Bay (Orth et al. 1979, Stevenson and Confer 1978).

TABLE III-10

Rank Analysis for Dominant Species Based on 110 Samples.

Species	Mean Total Biological Index Per Sample	Frequency of Occurrence in 110 Samples
1. *Heteromastus filiformis(P)*	1.83	107
2. *Spiochaetopterus oculatus(P)*	1.72	92
3. *Streblospio benedicti(P)*	1.43	63
4. *Nereis succinea(P)*	1.36	82
5. *Polydora ligni(P)*	1.20	61
6. *Ampelisca vadorum(A)*	1.11	74
7. *Oligochaetes*	0.99	76
8. *Ampelisca abdita(A)*	0.95	69
9. *Prionospio heterobranchia(P)*	0.74	52
10. *Edotea triloba(I)*	0.62	64
11. *Exogone dispar(P)*	0.50	43
12. *Macoma balthica(B)*	0.45	19
13. *Scoloplos robustus(P)*	0.33	75
14. *Lumbrineris tenuis(P)*	0.25	20

P= Polychaete, *A*= Amphipod, *I*= Isopod, Bivalve.

From: Orth, 1973 (Ches. Sci. 14).

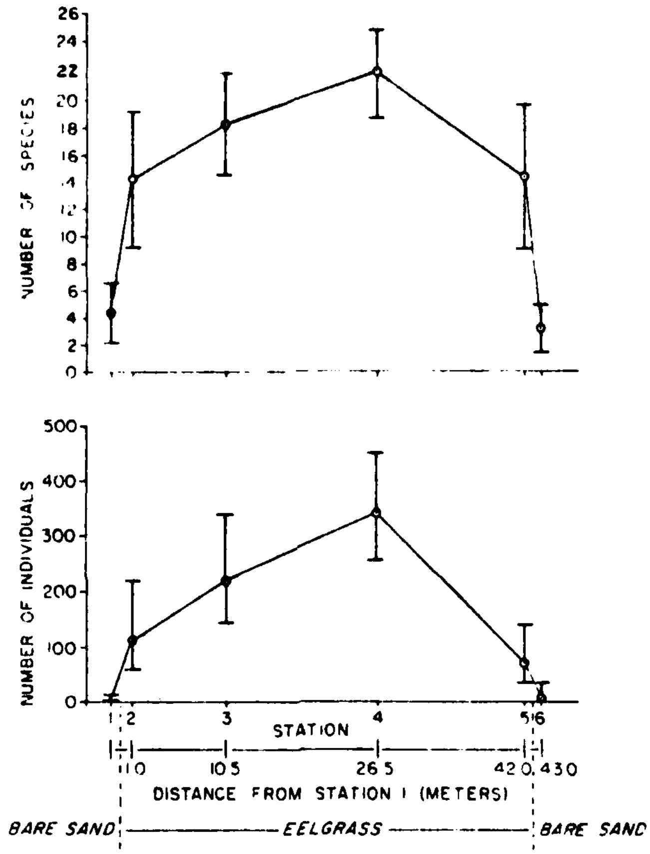


Figure III- 11

RELATIONSHIP BETWEEN BENTHIC INFAUNA AND EELGRASS ALONG AN SAV TRANSECT

Source: Orth, 1977

TABLE III-11

Frequency of Epifaunal Species Found on Zostera Marina in Virginia
Source: Marsh 1973

Rank By No.	Species	No.	% fauna	Cumul. %	Frequency in 48 samples
1	*Bittium varium*	43795	26.20	26.20	48
2	*Paracerceis caudata*	17379	10.40	36.60	48
3	*Crepidula convexa*	16801	10.05	46.65	48
4	*Ampithoe longimana*	10505	6.29	52.94	48
5	*Erichsonella attenuata*	10099	6.04	58.98	48
6	*Polydora ligni*	8114	4.85	63.83	24
7	*Elasmopus pocillimanus*	7611	4.55	68.38	47
8	*Brania clavata*	7033	4.21	72.59	29
9	*Cymadusa compta*	5202	3.11	75.70	48
10	*Ercolania fuscata*	4327	2.59	78.29	7
11	*Sabella microphthalmc*	3502	2.10	80.39	37
12	*Caprella penantis*	3498	2.09	82.48	37
13	*Balanus improvisus*	2754	1.65	84.13	32
14	*Odostomia impressa*	2636	1.58	85.71	41
15	*Nereis succinea*	2433	1.46	87.17	45
16	*Euplana gracilis*	2280	1.36	85.53	32
17	*Molgula manhattensis*	2235	1.34	89.87	16
18	*Gammarus mucronatus*	2226	1.33	91.20	34
19	*Elysia catula*	2070	1.24	92.44	41
20	*Aiptasiomorpha luciae*	1863	1.11	93.55	24
21	*Platynereis dumerilii*	1710	1.02	94.57	41
22	*Podarke obscura*	1365	.82	95.39	27
23	*Urosalpinx cinerea*	766	.46	95.85	33
24	*Mitrella lunata*	595	.36	96.21	44
25	*Odostomia bisuturalis*	501	.30	96.51	42
26	*Stylochus ellipticus*	485	.29	96.80	23
27	*Hydroides hexagona*	471	.28	97.08	16
28	*Batea catharinensis*	415	.25	97.33	8
29	*Melita appendiculata*	383	.23	97.56	13
30	*Idotea baltica*	348	.21	97.77	28
31	*Zygonemertes virescens*	340	.20	97.97	25
32	*Tetrastemma elegans*	330	.20	98.17	31
33	*Corophium acherusicum*	306	.18	98.35	22
34	*Doridella obscura*	287	.17	98.52	10
35	*Triphora nigrocincta*	274	.16	98.68	20
36	*Neomysis americana*	261	.16	98.84	14
37	*Hippolyte pleuracantha*	244	.14	98.98	20
38	*Paracaprella tenuis*	144	.09	99.07	20
39	*Rudilemboides* sp.	137	.08	99.15	19
40	*Corophium simile*	123	.07	99.22	26
41	*Odontosyllis fulgurans*	121	.07	99.29	14
42	*Exogone dispar*	116	.07	99.36	15
43	*Colomastix* sp.	110	.07	99.43	13
44	*Polycerella conyna*	88	.05	99.48	7
45	*Ampelisca vadorum*	84	.05	99.53	9
46	*Callipallene brevirostris*	82	.05	99.58	12
47	*Mysidopsis bigelowi*	79	.05	99.63	8
48	*Edotea triloba*	64	.04	99.67	18
49	*Ampelisca* sp.	64	.04	99.71	15
50	*Tenellia fuscata*	58	.03	99.74	8
51	*Anadara transversa*	54	.03	99.77	19
52	*Mya arenaria*	45	.03	99.80	14
53	*Pista palmata*	43	.03	99.83	10
54	*Lepidonotus variabilis*	42	.03	99.86	11
55	*Ampelisca abdita*	35	.02	99.88	5

TABLE III-11
Page 2

Rank By No.	Species	No.	% fauna	Cumul. %	Frequency in 48 samples
56	*Amphiporus ochraceus*	24	.01	99.89	9
57	*Prionospio heterobranchia*	20	.01	99.90	6
58	*Neopanope texana sayi*	20	.01	99.91	8
59	*Odostomia dux*	17	.01	99.92	9
60	*Nereiphylla fragilis*	16	.01	99.93	9
61	*Anachis avara*	9	.01	99.94	6
62	*Nassarius vibex*	9	.01	99.95	7
63	*Stenothoe minuta*	9	.01	99.96	4
64	Turbellarian #2	7			1
65	*Palaemonetes pugio*	7			7
66	*Doris verrucosa*	5			3
67	*Palaemonetes vulgaris*	4			4
68	*Eumida sanguinea*	4			4
69	*Crangon septemspinosa*	4			2
70	*Amphiporus caecus*	3		99.97	1
71	*Tubulanus pellucidus*	3			2
72	*Eupleura caudata*	3			2
73	*Leptochelia savignyi*	3			2
74	*Monoculodes edwardsi*	3			1
75	Turbellarian #3	2		99.98	2
76	*Tetrastemma jeani*	2			2
77	*Eteone heteropoda*	2			2
78	*Potamilla neglecta*	2			2
79	*Hermaea cruciata*	2			1
80	*Turbonilla interrupta*	2			2
81	*Caprella equilibra*	2			2
82	*Ericthonius brasiliensis*	2			1
83	*Stenothoe gallensis*	2			1
84	*Diadumene leucolena*	1		99.99	1
85	Turbellarian #1	1			1
86	*Tetrastemma vermiculus*	1			1
87	*Sabellaria vulgaris*	1			1
88	*Scoloplos fragilis*	1			1
89	*Ichthyobdella rapax*	1			1
90	*Crepidula plana*	1			1
91	*Nassarius obsoletus*	1			1
92	*Cratena pilata*	1			1
93	*Haminoea solitaria*	1			1
94	*Oxyurostylis smithi*	1			1
95	*Corophium tuberculatum*	1			1
96	*Lysianopsis alba*	1			1
97	*Melita nitida*	1			1
98	*Callinectes sapidus*	1			1
99	*Libinia dubia*	1			1
100	*Dipteran larva*	1		100.00	1

SAV beds are also important to more motile organisms in the Chesapeake Bay. Merriner and Boehlert (1979), studying fish communities in relation to SAV, divided up the community into: 1) fish eggs, larvae, post larvae and pelagic juveniles, 2) resident fishes, and 3) migratory predators.

Delineating between _Zostera_ and _Ruppia_ beds, and sand, they found that the greatest catch of migratory predators was in the _Zostera_ beds (48%). Of the fish considered residents, spot (_Leistomus xanthurus_), was the most abundant (Table III-12).

A number of SAV species, such as _Zostera marina_, _Ruppia maritima_, and _Potamogeton perfoliatus_ are the preferred food of certain waterfowl. Rawls (draft) examined the stomach of 1,179 waterfowl from the upper Chesapeake Bay and found _Potamogeton perfoliatus_ and _Ruppia maritima_ to be the most frequently found SAV species. Stewart (1962) also reported a high frequency of SAV species in the stomachs of waterfowl. Besides waterfowl, muskrats and fish are also reported to feed on SAV (Willner _et al_. 1975). As primary producers, SAV also contribute to the organic detrital load of the Bay.

Submerged aquatic vegetation was apparently more common in the past than it is today. Although a catastrophic decline in one species, _Zostera marina_, during the 1930's has been documented for the Atlantic coastal region (Cottam 1935, _In_: Cottam and Munro), most of the records of SAV distribution and abundance in the Chesapeake Bay date from the 1950's. The historical information regarding trends in submerged aquatic vegetation in the Bay has been well documented by Stevenson and Confer (1978). Most of the data available was for SAV in Maryland waters, and much of this data was collected by the Maryland Wildlife Administration and the Migratory Bird and Habitat Research Laboratory (MBHRL) of the U.S. Fish and Wildlife Service.

The historical data show a general decline in SAV distribution and abundance. Out of 21 river systems where SAV was reported

TABLE III-12

Number of Resident Fish Associated With an SAV Community (/100 m^2)

	March			April			May			June			July			August		
	Z	R	S	Z	R	S	Z	R	S	Z	R	S	Z	R	S	Z	R	S
Anguilla rostrata							1.97										0.22	
Alosa aestivalis				3.15	0.44	1.90												
A. pseudoharengus													0.58					
Brevoortia tyrannus					1.40	2.75	70.08	69.24	34.45		0.95	10.31	0.31	0.26		0.22	0.65	
Anchoa mitchilli	0.56	0.97	1.30	10.53	22.93	27.46	27.17	33.24	52.15	94.49	57.22	50.0	31.60	21.78	42.68	49.73	49.20	14.47
Rissola marginata				0.79	1.23		0.39	0.39						0.26	0.26			
Hemiramphus brasiliensis							0.79	0.66										
Lucania parva							8.27	1.05	0		0.95							
Menidia menidia	9.02	8.65	0.43	2.36	0.26	0.33											0.22	
Membras martinica				1.18	0.96	3.28	1.97	1.71	2.88	5.51	1.54	0.35	4.72	1.57	2.53	3.31	1.95	
Gasterosteus aculeatus	0.43																	
Syngnathus fuscus							3.15	1.57		1.74	0.71		3.60	4.46	1.13	3.94	2.60	0.22
Centropristis striata								0.39										
Orthopristis chrysoptera															.29			
Bairdiella chrysoura																2.01	1.30	0.22
Cynoscion nebulosus																1.34		1.10
C. regalis																1.08	0.65	
Leiostomus xanthurus				225.2	132.48	74.67	37.80	5.39	10.49	5.80	8.39	3.51	1.74		4.61	1.95		0.66
Menticirrhus americanus																0.22		0.66
Gobiosoma ginsburgi				0.39			0.39											
Peprilus sp.																0.22		
Paralichthys dentatus								0.39		0.29	0.24	0.35						
Scopthalmus aquosus	0.56																	
Pseudopleuronectes americanus								0.66					0.31					
Trinectes maculatus										0.29								
Sphoeroides maculatus																0.22		0.22

Source: Merriner and Boelhert 1979

AD-A125 261 CHESAPEAKE BAY LOW FRESHWATER INFLOW STUDY BIOTA ASSESSMENT PHASE I VOLUME I(U) WESTERN ECO-SYSTEMS TECHNOLOGY INC BOTHELL WA G B SHEA ET AL. AUG 80 2/3

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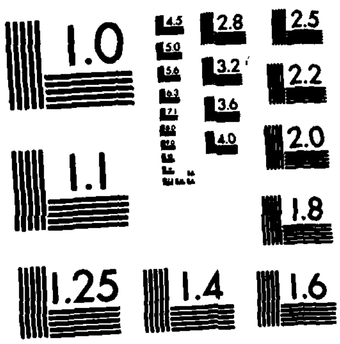

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

in 1971, 19 showed a decline in the percentage of sample sites with vegetation in 1977 (Table III-13). Bayley _et al_. (1978) documented the occurrence of dominant SAV species in the Susquehanna flats from 1958 - 1975 (Table III-14). Three of the species almost completely dissapeared from this area after 1972. Besides showing the decline of SAV on the Susquehanna flats, their data also document the increase and subsequent decline of Eurasian Watermill foil (_Myriophyllum spicatum_) at that site, a phenomenon which occurred throughout the Chesapeake Bay (Bayley _et al_. 1968). In the Virginia section of the Chesapeake Bay, Orth _et al_. (1979), compared the acreage of _Zostera_ on historical and recent aerial photographs. These photographs show a distinct decline in acreage of _Zostera_ between 1937 and 1978.

In 1978, two Bay-wide SAV surveys were done as part of the U.S. Environmental Protection Agency's Chesapeake Bay Program (U.S. EPA 1979). Anderson and Macomber (in press) in Maryland, and Orth _et al_. (1978) in Virginia used aerial photography and ground sampling to determine the distribution of SAV in the Bay. This information is shown in the Map Atlas (see Section V.G.).

In Maryland, SAV species identification was made at approximately 85 locations where aerial photography showed the presence of SAV beds. In Virginia, ground surveys were made at large beds of _Zostera_ and _Ruppia_ that were located by aerial photography as well as in less aline areas where little vegetation was observed by aerial photography. Table III-15 compares the frequency of occurrence of SAV species in these two studies, as well as data from the 1978 SAV survey (taken from MBHRL field sheets). Only sites reported to be vegetated are shown. Table III-15 also shows the information from the three sources combined.

Three associations of SAV were numerically determined in the Virginia study, characteristic of waters that are fresh, less than 15 ppt salinity, and greater than 15 ppt salinity. These associations are dominated by a variety of genera including _Najas_, _Ceratophyllum_, _Elodea_ and _Potomogeton_ in fresh water; _Potomogeton_, _Zannichellia_, _Vallisneria_, _Callitriche_ and _Myriophyllum_ in brackish water; and _Zannichellia_ and _Ruppia_ in marine waters.

TABLE III-13

Frequency of Occurrence of Vegetated Samples and Indicated Change by River Systems. Migratory Bird and Habitat Research Laboratory Survey, 1971-1976[a]

Area code	River system	1971 % Veg.	1972 % Veg.	1973 % Veg.	1974 % Veg.	1975 % Veg.	1976 % Veg.	1977[b] % Veg.	Number of stations 71	72	73	74	75	76	77
1	Elk & Bohemia Rivers	6.67	0	0	0	0	0	0	15	16	16	16	16	16	16
2	Sassafras River	30.00	0	0	0	0	0	0	10	10	10	10	10	10	10
3	Howell & Swan Points	16.67	0	0	0	0	0	0	12	6	12	12	12	12	12
4	Eastern Bay	34.04	46.51	34.04	36.17	21.74	42.22	28	47	43	47	47	46	45	47
5	Choptank River	35.00	39.66	19.30	27.59	1.72	41.07	25	60	58	57	58	58	56	60
6	Little Choptank River	21.05	21.05	0	0	0	15.79	5	19	19	19	19	19	19	19
7	James Island & Honga River	44.12	35.29	2.94	5.88	5.88	8.82	3	34	34	34	34	34	34	34
8	Honga River	50.00	40.00	13.33	16.66	10.35	17.24	3	30	30	30	30	29	29	30
9	Bloodsworth Is.	37.50	22.73	10.87	11.63	6.98	2.22	4	40	44	46	43	43	45	46
10	Susquehanna Flats	44.44	2.70	0	13.51	11.11	8.57	11	27	37	37	37	36	35	37
11	Fishing Bay	8.00	4.00	0	0	0	0	0	25	25	25	25	24	25	25
12	Nanticoke & Wicomico Rivers	0	0	0	0	0	0	0	30	30	30	31	30	30	31
13	Manokin River	40.00	46.67	13.33	20.00	7.14	6.67	20	15	15	15	15	14	15	15
14	Patapsco River	0	5.00	4.76	9.52		9.52	14	21	20	21	21	0	21	21
15	Big & Little Annemessex Rivers	70.00	60.00	30.00	57.89	33.33	30.00	30	20	20	20	19	18	20	20
16	[illegible]ler & Bush R[illegible] Headwaters	11.11	0	0	0		0	11	9	8	7	9	0	9	9
17	Pocomoke Sound (Maryland)	18.18	10.00	4.76		15.00	9.09	10	22	20	21	0	20	22	22
18	Magothy River	33.33	0	16.67	16.66	-	16.67	25	12	12	12	12	0	12	12
19	Severn River	40.00	20.00	26.67	26.67	-	46.15	20	15	15	15	15	0	13	15
20	Patuxent River	2.00	4.26	0	4.00	0	2.04	2	50	47	50	50	47	49	50
21	Back, Middle & Gunpowder Rivers	13.64	4.55	4.55	4.55	9.09	4.55	9	22	22	22	22	22	22	22
22	Curtis & Cove Points	0	0	0	0	0	0	0	20	19	19	19	6	21	21
23	South, West & Rhode Rivers	0	0	0	0	0	12.50	0	8	10	10	8	8	8	10
24	Chester River	61.11	36.11	26.47	23.52	25.00	25.71	38	36	36	34	34	36	35	36
25	Love & Kent Points	0	0	0	17.50	0	0	0	8	8	8	8	8	8	8
26	Smith Island (Maryland)	64.71	45.46	25.00	35.29	22.22	35.29	24	17	11	12	17	17	17	17
	Total	28.53	20.98	10.49	14.85	8.70	14.97	12	624	615	629	611	552	628	645

[a] U.S. Fish and Wildlife Service Migratory Bird and Habitat Research Laboratory files 1977
[b] Preliminary results (Stotts, personal communication)

Source: Stevenson and Confer (1978).

TABLE III-14

Occurrence of Dominant Rooted Sumberged Aquatic Plant Populations in the Susquehanna Flats Over 9 Years.

Dominant Plants	Rating Category	1967	1968	1969	1970	1971	1972	1973	1974	1975
Myriophyllum spicatum	A[1]	20	17	7	14	5	0	0	0	0
	C[1]	16	10	15	7	16	0	0	5	3
	O[1]	12	9	5	4	6	3	2	8	5
	R[1]	11	20	30	19	25	13	23	26	13
	V[2]	163	136	113	104	105	18	27	57	32
Vallisneria americana	A	26	28	4	8	23	0	0	0	0
	C	23	29	21	24	28	0	0	0	0
	O	4	7	16	9	10	0	0	0	0
	R	0	8	21	13	11	0	0	0	0
	V	181	221	132	135	207	0	0	0	0
Najas spp.	A	21	14	3	3	9	0	0	0	0
	C	18	24	6	9	10	0	0	0	0
	O	9	3	6	3	5	0	0	0	0
	R	1	14	18	7	9	0	0	1	0
	V	152	148	60	52	85	0	0	1	0
Elodea canadensis	A	4	20	12	7	7	0	0	0	0
	C	17	17	10	14	12	0	0	0	0
	O	2	9	15	9	8	0	0	0	0
	R	10	11	23	12	16	0	0	0	0
	V	81	160	131	100	96	0	0	0	0

After Bayley et al. 1978 (Est.)

[1]Number of times species was rated in each category. Differences due to the varying number of stations for the duration of the study.

[2]is a rating value that gives an estimate of the total amount of plant material according to the following: 4-abundant; 3-common; 2-occasional; and 1-rare. These values are multiplied by the number of times each category appeared for the species each year.

TABLE III-15

Relative Frequency of SAV Species in Maryland, Virginia and Combined Samples (expressed in percentages).

Species	Maryland A[1]	Maryland B[2]	Virginia[3]	Combined[4]
Ruppia maritima	70	39	12	36
Potamogeton perfoliatus	27	34	6	22
Zannichellia palustris	17	44	42	36
Potamogeton pectinatus	15	41	6	21
Elodea candensis	12	12	13	12
Najas spp.	9	2	14	6
Chara spp.	9	-	2	3
Myriophyllum spicatum	7	40	3	17
Zostera marina	5	-	12	6
Vallisneria americana	5	8	13	9
Ceratophyllum demersum	-	-	35	14
Nitella spp.	-	-	12	5
Callintriche verna	-	-	6	3
Potamogeton crispus	-	-	5	2
Potamogeton filiformis	-	-	3	1
Elodea nuttalli	-	-	1	1
Potamogeton nodosus	-	-	1	1
Potamogeton foliosus	-	-	1	1

1). Calculated from MBHRL field sheets.

2). Calculated from Mapsly, Anderson and Macomber, (in press)

3). Orth et al. (1979)

4). Weighted Average

Although the Virginia waters of the Chesapeake Bay contained about 8400 hectares of Zostera/Ruppia beds, the density in these beds varied considerably (Orth et al. 1978). This biomass and production data, as well as distribution information, are important in SAV research. Nichols et al. (1980) determined biomass volumes for SAV in the fresh-oligohaline zones near the Gunpowder River. Maximum standing crop was contributed by Myriophyllum spicatum in June, with 108.16 g/m^2. Boynton et al. (1979), in preliminary results, found Ruppia marina biomass to be 69.5 g/m^2 in Eastern Bay in July. Orth et al. (1979) reported August mean standing crops of Zostera and Ruppia of 78.2 g/m^2 and 43.2 g/m^2 respectively in the meso-polyhaline areas of the Bay.

The major effects on SAV's from low flow are expected to be due to declines in turbidity, nutrient input from non-point sources, and possibly toxic compounds (i.e. herbicides). Since dilution of point-source pollutants will increase, however, this must be treated as a confounding influence on a general decrease in organic compounds.

4. Emergent Aquatic Vegetation

The Chesapeake Bay tidal wetlands system comprises one of the great tidal wetlands systems in the United States. In Maryland, tidal wetlands have a total area of about 210,000 acres, while in Virginia there are more than 90,000 acres of tidal wetlands.

"Tidal wetlands" is the term for the area where aquatic and terrestrial ecosystems meet, and where the water level varies in response to tidal fluctuations. One definition of wetlands is (Cowardin et al. 1977):

> Land where the water table is at, near or above the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes.

The tidal wetland zone, which is an ecotone between the aquatic and terrestrial ecosystem, is the habitat for a great number of plants and animals. Vegetated tidal wetlands are often categorized by the presence or absence of certain species of plants, either alone or in commonly encountered associations. The State of Maryland classified tidal wetlands as part of the wetlands inventory of 1967 - 1968. The types of wetlands in this classification and a brief discussion of each type follow (Metzgar 1973):

Type 12 - Coastal shallow fresh marsh. These marshes may be covered by up to 6 inches of water and are usually found along tidal rivers, sounds and estuaries.

Type 13 - Coastal deep fresh marsh. Water may cover this type of marsh with from one-half to three feet of water at mean high tide. Type 13 marshes are found on the water-side of type 12 marshes and are bordered by deeper water.

Type 14 - Coastal open fresh water. These are essentially open water areas, often containing submerged aquatic vegetation, with fringing emergent vegetation.

Type 16 - Coastal salt meadow. This type of marsh is typically composed of Spartina patens and Distichlis spicata. The elevation of this marsh type results in flooding infrequently enough that evaporation may result in high local salinities. Fringing areas of patches of Spartina alterniflora may be present between the type 16 marsh and open water.

Type 17 - Irregularly flooded salt marsh. This type of marsh is composed primarily of Juncus roemerianus (needle rush), and as the category name implies, is irregularly flooded. Type 17 marshes are commonly associated with the type 16 marsh (Spartina patens/Distichlis spicata), and fringing area of Spartina alterniflora.

Type 18 - Regularly flooded salt marsh. High tides cover the soil of this marsh type, which is often found as fringing marsh. In areas of greater tidal amplitude, type 18 marshes occupy a greater area.

The numbers of marshes of each type, and the acreage of each type, varies by county, depending upon the hydrology, elevation and salinity of the area. The amount of destruction of wetlands also influences the total. Table III-16 lists the amount of area of each marsh type for each Maryland County with tidal wetlands (with the exception of Worcester County, which is not on the Chesapeake Bay). Dorchester and Somerset Counties have the greatest total acreage by this inventory, followed by Wicomico County.

A more recent study of Maryland's tidal wetlands was done in 1975 - 1978 based on 1971 aerial photography (Maryland Department of Natural Resources, unpublished). Table III-17 shows the revised marsh typing scheme developed in this study. This typing scheme allows a much more detailed breakdown of the various types of marshes found in Maryland. The marsh categories with the largest acreage in Maryland are the Spartina patens/ Distichlis spicata marsh (type 41), the Juncus roemerianus (type 43), the Scirpus marsh (Type 47), and the Spartina alterniflora marsh (type 51). Table III-18 lists the areas of each marsh type by county. In general, the acreages are much smaller as defined by the more recent aerial photograph survey.This may be due to the differences in technique and in part due to continued destruction of wetlands in recent years. If marsh area is examined by watershed, three Eastern Shore watersheds — the Choptank, the Nanticoke, and the Pocomoke — represent approximately 70% of the total area.

Tidal marshes in Virginia have been inventoried in a series of surveys beginning in the early 1970's by the Virginia Institute of Marine Science (VIMS Special Report Nos. 45, 49, 53, 58, 59, 62, 63, 64, 108, 137, 138, 139, 167, 207, and 208). For this survey, Virginia marshes were categorized into 12 types, 10 of which are based upon dominant species (dominant = 50% area) (Silberhorn et al. 1974). These categories are as follows:

Type I - Spartina alterniflora community (saltmarsh cordgrass)

Type II - Spartina patens/Distichlis spicata community (saltmeadow cordgrass/saltgrass)

TABLE III-16

Tidal Wetland Acreage Summary by County and By Wetland Type. Based on the 1967 - 1968 Maryland Wetlands Inventory. Source: Metzgar 1973

	6[a]	7[b]	12	13	14	16	17	18	Total
Anne Arundel	580	3,862	1,929		24	321			6,716
Baltimore	80	67	2,734						2,881
Calvert	17	948	2,222		43	875			4,105
Caroline	122	3,335	2,353						5,810
Cecil	126	653	2,400						3,179
Charles	6	3,521	7,022			418			10,967
Dorchester	1,916	28,299	27,296			26,252	36,881		120,644
Harford			8,424						8,424
Kent	506	591	3,382		116	2,144			6,739
Prince Georges	86	4,125	2,835	123					7,169
Queen Ann	71	1,648	1,759	46	416	3,816	334		8,090
St. Mary		725	936		325	1,998			3,984
Somerset	9	3,435	712			27,270	26,504		57,930
Talbot	44	359	4,135			3,143	653	267	8,601
Wicomico	792	4,100	398			10,945	2,227		18,507
Worcester	1,172	11,643	1,177			685		12,314	26,991

a : Shrub Swamp

b : Wooded Swamp

TABLE III-17

Vegetation Typing Scheme Maryland Coastal Wetlands Study (Source: Maryland DNR unpubl.)

SHRUB SWAMP CATEGORY

11 Rosa palustris
12 Alnus serrulata/Salix nigra (Alder/Willow)
13 Acer rubrum/Fraxinus spp. (Maple/Ash)

WOODED SWAMP CATEGORY

21 Taxodium distichum (Cypress)
22 Acer rubrum/Fraxinus spp. (Maple/Ash)
23 Pinus spp.

FRESH MARSH CATEGORY

30 Polygonum spp./Leersia oryzoides
31 Nuphar advena
32 Pontederia cordata/Peltandra virginica
33 Acpris calamus
34 Typha spp.
35 Hibiscus spp.
36 Zizania aquatica
37 Scirpus spp.
38 Spartina cynosuroides
39 Phragmites australis

BRACKISH HIGH MARSH CATEGORY

41 Spartina patens/Distichlis spicata
42 Iva frutescens/Baccharis halimifolia/Spartina patens (S.patens only as an understory with the shrubs being dominant. This type is in recognition of a common, or frequent, association recognized herein as a type).
43 Juncus roemerianus

BRACKISH HIGH MARSH CATEGORY (cont'd)

44 Typha spp.
45 Hibiscus spp.
46 Panicum virgatum
47 Scripus spp.
48 Spartina cynosuroides
49 Phragmites australis

BRACKISH LOW MARSH CATEGORY

51 Spartina alterniflora (No growth forms differentiated)

SALINE HIGH MARSH CATEGORY

61 Spartina patens/Distichlis spicata
62 Juncus roemerianus

SALINE LOW MARSH CATEGORY

71 Spartina alterniflora
72 Spartina alterniflora (low growth form) Salicornia/Limonium

TABLE III-18

Tidal Wetlands Acreage Summary - County (Source: Maryland DNR unpubl.)

Vegetation Types (Acreage)*

COUNTY	11	12	13	21	22	23	30	31	32	33	34	35	36	37	38	39
Anne Arundel	35	64	32	-	16	1	228	43	31	14	151	6	113	-	-	23
Baltimore	-	10	6	-	3	-	147	3	129	25	835	81	35	431	57	140
Calvert	-	6	18	-	-	-	25	6	79	-	195	11	28	4	14	66
Caroline	3	-	2	-	871	-	196	466	572	2	393	7	6	35	12	1
Cecil	-	124	157	-	77	-	305	10	413	61	904	60	112	25	-	98
Charles	7	1	165	-	11	3	248	26	155	-	186	18	-	104	310	-
Dorchester	-	-	906	-	5727	806	173	430	283	12	934	11	132	1038	85	7
Harford	1	13	59	-	104	73	127	19	496	146	2909	800	158	957	247	176
Kent	-	-	354	-	83	-	26	17	229	5	636	54	-	23	223	17
Prince Georges	-	[illegible]	40	-	80	-	740	141	20	3	421	8	105	78	108	103
Queen Annes	-	-	4	-	7	-	7	-	86	-	152	9	-	-	23	9
Somerset	-	1	67	553	519	181	63	-	61	11	132	26	-	-	190	1
St. Marys	-	22	37	-	1	14	12	-	-	-	-	8	-	-	-	.
Talbot	5	-	27	-	188	-	40	118	381	6	667	44	5	110	172	2
Wicomico	-	-	115	-	1304	171	180	352	952	146	409	33	79	3	284	24
Worcester	-	-	41	3595	2400	4	407	143	38	-	103	80	3	-	177	-
TOTAL	51	524	2025	4154	11791	1253	2924	1774	3925	431	9018	1256	776	2808	1994	747

COUNTY	41	42	43	44	45	46	47	48	49	51	61	62	63	71	72	TOTAL
Anne Arundel	315	313	-	369	12	9	21	21	82	380	-	-	-	-	-	2299
Baltimore	47	20	-	30	8	20	39	0	4	31	-	-	-	-	-	2103
Calvert	303	190	2	664	7	10	220	447	36	331	-	-	-	-	-	2662
Caroline	1	13	-	196	1	120	203	232	-	35	-	-	-	-	-	3367
Cecil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2346
Charles	349	276	7	237	43	-	669	970	3	320	-	-	-	-	-	4108
Dorchester	12728	3361	23131	2330	26	1301	14891	2167	488	12280	-	-	-	-	-	83247
Harford	2	2	-	-	-	150	-	-	-	0	-	-	-	-	-	6439
Kent	704	524	7	192	34	52	296	13	61	398	-	-	-	-	-	3923
Prince Georges	72	2	-	272	-	-	326	274	8	8	-	-	-	-	-	2801
Queen Annes	935	897	281	493	15	18	65	212	105	104	-	-	-	-	-	3422
Somerset	13236	3057	22543	197	4	253	1656	1093	38	6901	-	-	-	-	-	50789
St. Marys	605	640	102	120	74	12	186	472	9	653	-	-	-	-	-	3167
Talbot	552	1076	122	380	27	80	46	314	78	341	-	-	-	-	-	4781
Wicomico	1253	133	2490	66	28	112	199	1981	17	3271	-	-	-	-	-	13588
Worcester	18	55	-	46	2	28	348	-	26	26	2304	1780	121	95	9449	21289
TOTAL	31072	10559	48685	5691	281	2165	18965	8196	955	25079	2304	1780	121	95	9449	210358

* Zero (0) indicates the type exists, but in amounts </acre.

Type III - Juncus roemerianus community (black needle-rush)

Type IV - Iva frutescens/Baccharis halimifolia community (salt bush)

Type V - Spartina cynosuroides community (big cordgrass)

Type VI - Typha spp. community (cattail)

Type VII - Peltandra virginica/Pontederia cordata community (arrow arum/Pickerel weed)

Type VIII - Phragmites autralis community (reed grass)

Type IX - Nuphar luteum community (yellow pond lily)

Type X - Salicornia spp. community (saltwort)

Type XI - Freshwater mixed

Type XII - Brackish water mixed

To classify an entire marsh as a certain type, the marsh surveys had to determine the amount of acreage made up of various species. Table III-19 lists the acreage covered by particular marsh species in seventeen Virginia counties and the total acreage covered by those species. Juncus roemerianus, Spartina alterniflora, and Spartina cynosuroides are the three species with the greatest total acreage.

Fresh and salt marshes give way to uplands as the elevation of the land increases. The transition to uplands species involves two primary factors. At the lower level of the transition zone, the species composition is determined by the frequency of tidal inundation. At the upper level of the transition zone competition with upland species limits the species composition (Boon et al. 1977).

Salt marshes in the Chesapeake Bay have a lower zone, usually composed of Spartina alterniflora, which receives daily tidal inundation, and an upper zone where the tides do not reach on a daily basis. The upper zone usually consists of a short grass meadow, composed of Spartina patens and Distichlis spicata, frequently interposed with Juncus roemerianus. Other, less abundant species may be present. The transition zone between

TABLE III-19

Acreage of Tidal Wetlands and Dominant Species in 17 Virginia Counties.

County	*Spartina alterniflora*	*Juncus roemerianus*	*Spartina patens* *Distichlis spicata*	*Iva frutescens* *Baccharis halimifolia*	*Spartina cynosuroides*	*Typha spp.*	*Phragmites australus*	*Peltandra virginica* *Pontederia cordata*	*Scirpus spp.*	*Other*	*Total*
Accomack (Bayside)	461	11421	2957	2110	2013	200	-	-	608	427	23918
Arlington, Fairfax, Alexandria	-	-	-	-	-	221	10	307	47	301	934
Caroline	-	-	-	-	-	9	-	41	4	431	485
Essex	15	-	58	32	2819	860	34	698	119	526	5214
Gloucester	257	945	691	435	264	104	-	36	78	269	6329
King George	118	-	10	43	570	291	-	108	57	874	2122
Lancaster	328	328	61	71	233	-	-	-	-	158	1190
Mathews	839	1248	552	230	41	-	-	-	-	4	2937
New Kent	709	-	-	8	2159	109	-	483	99	1706	5467
Newport News, Fort Eustis	929	1050	314	118	332	13	3	9	15	86	2883
Northampton (Bayside)	836	126	142	218	33	38	1	-	5	9	1404
Northumberland	213	400	309	132	121	-	-	-	-	351	1560
Spotsylvania	-	-	-	-	-	-	-	-	-	7	7
Stafford	-	-	-	13	30	321	-	236	8	728	1337
Westmoreland	413	10	137	285	496	420	-	235	34	527	2590
York, Poquoson	2656	1468	1797	597	218	-	-	-	-	-	6991
TOTAL	11474	16996	7028	4274	9329	2586	48	2153	1074	6404	65368

Data compiled from VIMS Marsh Inventories 1973-1979.

salt marsh and uplands is often marked by *Iva frutenscens* and *Baccharis halimifolia*, with *Baccharis* being the most landward plant.

The fresh water marsh - upland boundary is more difficult to identify (Boon *et al*. 1977). This is probably due to the absence of the salinity factor in fresh water marsh delineation. Patterns of zonation within the marsh are also difficult to identify, which is made even more difficult by the greater species diversity in fresh water marshes (Good, Whigham and Simpson 1978). Prevalent zonation and associations are between *Nuphar luteum* in deeper water and *Peltandra virginica*/*Pontederia cordata* above it. Above this zone the species can become quite diverse, and, in the absence of relief, the marsh may merge very gradually into swamp forest or wet upland.

Tidal marshes in the Chesapeake Bay area are productive systems. Flemer *et al*.(1978) determined standing crop in two tributaries of the Chesapeake Bay. Samples from the Patuxent River averaged abount 1,416 g/m^2 while samples from Parker Creek, the other tributary study, averaged about 895 g/m^2. The standing crops of individual community types ranged from about 22 g/m^2 to 2,160 g/m^2 (Table III-20). Mendelssohn and Marcellus (1976) compared the productivities of two marshes in the York River estuarine system with a marsh on the ocean side of Virginia's eastern shore. The two York River marshes had productivities of 563 and 572 g/m^2, while the eastern shore marsh had a productivity of 362 g/m^2. Cahoon (1975), working in a marsh located on the Choptank estuary, found *Typha angustifolia* to be the most productive species in the marsh, with a biomass of 985 g/m^2. Least productive was the *Hibiscus moscheutos* zone, with a biomass of 516 g/m^2.

Most of the primary production of tidal marshes enter the detrital food web. Heinle and Flemer (1976) reported evidence that little detritus (particulate carbon) was exported from poorly flooded marshes along the Patuxent estuary. Marshes that under-

TABLE III-20

Biomass of Marsh Vegetation in Two Tributaries of the Chesapeake Bay, Maryland.

	Dry weight (gm) by site by date (month, day)							
	Iron Pot Landing				Jug Bay		Penno	
Community Type	Live	Dead	Live	Dead	Live	Dead	Live	Dead
	August 16		August 27		August 16		August 14	
Peltandra sp. and Polygonum arifolium	-	-	-	-	-	-	988	132
Phragmites australis	-	-	1498	230	811	130	1792	680
Spartina cynosuroides	-	-	-	-	-	-	951	241
Typha sp. and Acnida sp.	1238	37	1346	391	-	-	-	-
Typha sp. and Sagittaria sp.	-	-	-	-	1033	268	-	-
Zizania aquatica and Acnida sp.	1160	22	1349	120	-	-	-	-
Zizania aquatica and Peltandra sp.	-	-	-	-	909	73	-	-
Zizania aquatica and Pontederia sp.	-	-	-	-	1023	77	-	-

	Gott's						Bowen's	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead
	July 2&4		July 30 & August 2		Sept.		August 15	
Phragmites australis	-	-	-	-	-	-	1992	326
Scirpus olneyi	1141	358	894	91	602	445	844	314
Spartina cynosuroides	1952	607	2160	137	1208	556	1650	1232
Typha spp.	2338	167	934	113	959	202	1496	814

	Parker Creek	
	August 20, 22 & 23	
Scirpus olneyi	514	212
Spartina cynosuroides	705	257
Spartina patens and Distichlis spicata	680	1209
Typha sp.	1170	1113

Spartina cynosuroides reported as S. alterniflora in Johnson, 1970 (see Flemer et al. 1970 for primary citation).

Source: Flemer et al. (1978).

went ice scouring in winter, with a greater flooding rate, exported the most detritus to the estuary. There is strong evidence that estuarine organisms, such as the copepod Eurytemora affinia, utilize detritus (or the micro-organisms it supports) as a food source. Fresh water marshes might function differently than salt marshes in terms of export from the marsh system. Odum and Heywood (1978) have demonstrated that Peltandra virginica, a fresh water species, and other fresh marsh species, undergo rapid decomposition. A salt marsh species, Spartina alterniflora, slowed significantly slower decomposition rates than Peltandra. They suggest that much of the production of fresh water marshes might be released rapidly as dissolved organics. Dissolved organic material is also important in bracksih marshes, as Stevenson et al.(1976) have shown. When dissolved organic and inorganic nitrogen are considered together, the net flow of nitrogen is to the estuary. They also found phosphorus to have a net flux from the brackish marsh to the estuary.

Tidal wetlands are extremely valuable as habitat and as food sources for a large number of aquatic and terrestiral organisms. Muskrats and nutria are marsh residents, while numerous fish utilize the ponds and meanders of the marsh (Table III-21). Migratory waterfowl depend on tidal wetlands to a large extent (Stewart 1962) as do those waterfowl, such as black ducks, which nest on or near wetlands. Rails, herons, and several species of sparrows are also common in tidal wetlands.

Low Flow's affect EAV's mainly through shifts in salinity exposure. This will affect both the lower marshes through shifts in Venice system boundaries, and upper marshes through lowered freshwater runoff.

5. Benthic Organisms

Benthic organisms represent a major component of the estuarine ecosystem. Many benthic organisms represent primary food sources for fish, waterfowl, and crabs; other are of economic importance (Perry & Uhler 1976, Homer & Boynton 1977). They play major roles in nutrient recycling, sedimentation, sediment chemistry,

TABLE III-21

Fish Species Present and the Type of Utilization in a Dorchester County, Maryland Salt Marsh.

Fish species present		Usage			Season of Usage				Abundance		
Scientific name	Common name	Spawning	Nursery	Adult Feeding	Spring	Summer	Fall	Winter	High	Moderate	Low
**Petromyzon marinus*	sea lamprey	x									
Carcharhinus leucas	bull shark			x		x					
Carcharhinus milberti	sandbar shark			x		x					
Sphyrna zygaena	hammerhead shark			x		x					
Raja eglanteria	clearnose skate			x		x					
Rhinoptera bonasus	cownose ray			x		x					
**Acipenser oxyrhynchus*	Atlantic sturgeon	x			x				x		
**Alosa aestivalis*	blueback herring	x			x				x		
**Alosa mediocris*	hickory shad	x			x				x		
**Alosa pseudoharengus*	alewife	x			x				x		
**Alosa sapidissima*	American (white) shad	x			x				x		
Brevoortia tyrannus	Atlantic menhaden		x	x	x	x	x		x		
Dorosoma cepedianum	gizzard shad		x	x		x	x				x
Anchoa mitchilli	bay anchovy	x	x	x	x	x	x	x	x		
Cyprinus carpio	Carp			x			x	x			x
Notropis hudsonius	spottail shiner			x			x	x			x
Ictalurus catus	white catfish		x		x						x
Anguilla rostrata	American eel		x	x	x	x	x	x	x		
Strongylura marina	Atlantic needlefish	x	x	x	x	x	x	x	x		
Hyporhamphus unifasciatus	halfbeak		x	x		x	x		x		
Cyprinodon variegatus	sheepshead minnow	x	x	x	x	x	x	x	x		
Fundulus heteroclitus	mummichog	x	x	x	x	x	x	x	x		
Fundulus majalis	striped killifish	x	x	x	x	x	x	x	x		
Lucania parva	rainwater killifish	x	x	x	x	x	x	x	x		
Syngnathus fuscus	northern pipefish	x	x	x	x	x	x	x	x		
**Roccus americanus*	white perch	x	x	x	x	x	x	x	x		
**Roccus saxatilis*	striped bass	x	x	x	x	x	x	x	x		
Bairdiella chrysura	mademoiselle		x	x		x	x			x	
Cynoscion regalis	greytrout (weakfish)		x	x		x	x				x
Cynoscion nebulosus	spotted seatrout		x	x		x	x				x
Pomatomus saltatrix	bluefish		x	x		x	x		x		
Leiostomus xanthurus	spot		x	x		x	x		x		
Micropogon undulatus	Atlantic croaker		x	x		x	x				x
Pogonias cromis	black drum		x	x		x	x			x	
Sciaenops ocellata	channel bass (red drum)		x	x		x	x				x
Chasmodes bosquianus	striped blenny	x	x	x	x	x	x	x			x
Peprilus alepidotus	butterfish (Southern harvestfish)		x		x	x	x				x
Menidia menidia	Atlantic silverside	x	x	x	x	x	x	x	x		
Paralichthys dentatus	summer flounder		x			x					x
Pseudopleuronectes americanus	winter flounder		x		x			x		x	
Trinectes maculatus	hog choker	x	x	x	x	x	x	x	x		
Gobiesox strumosus	clingfish (skilletfish)	x	x	x	x	x	x	x			x
Opsanus tau	oyster toadfish	x	x	x	x	x	x	x		x	
Spheroides maculatus	northern puffer		x			x					
	Total	20	31	32	24	34	30	18	21	4	12

* Adults present during spawning migration, but not used as a spawning ground *per se*.

oxygen dynamics, and marine fouling (Reinharz et al. 1979, Nilsen et al. 1979, Boynton et al. 1978, Osborne et al. 1979). For this reason there exists a voluminous literature on Chesapeake Bay benthic invertebrates. However, many of these have dealt with a few commercially important species such as oysters or clams. Noncommercial species have not fared as well, and difficult groups such as meio- or microfauna are virtually unknown.

Benthic studies generally fall into two categories, those dealing with the autecology of selected species, and those dealing with composition, distribution, seasonality, and function of benthis faunal assemblages. A survey of some major Chesapeake benthic literature of the latter type is summarized in the remainder of this subsection.

Sessile epifauna are generally limited to hard substrates, and are extremely numerous in these environments. Many are termed "fouling organisms" which have been extensively studies because of the costs to marine industries, and potential damage to oyster beds. Beaven (1947) and Andrews (1953) investigated biofouling of oyster beds by a variety of organisms in the mid- and lower Bay, respectively. Both found wide variability in epifaunal communities depending on season, salinity and termperature of time of recruitment, and effects of competion for space.

Calder and Brehmer (1967) found the distinct seasonality in setting of epifauna to be correlated with water temperature; recruitment was highest in the warmer months (May through November). The community was dominated by barnacles in autumn, winter, and spring, while ascidians predominated in summer. Both competition for space and sedimentation affected survival of the various organisms.

Cory (1967) investigated epifaunal distribution, seasonality, and production along the salinity gradient of the Patuxent River. The number of species decreased upriver, but production was highest (over 6,500 g C/m^2y or eight times the annual productivity at the most down-river station). Productivity and recruitment were highest in the summer months. A later survey in the same tributary showed decreased epifaunal production upriver to be correlated with increased river runoff and the resulting increase in turbidity (Cory 1969).

Andrews (1973) found the catastrophic reduction in Bay salinities following Tropical Storm Agnes to have the greatest effect on mesohaline species; many were completely eliminated. Open niches were rapidly colonized by opportunistic species, many from the oligohaline region. Recovery was quickest for those species with pelagic larvae.

Larsen (1974) investigated the oyster reef community in the middle James River, identifying 142 species from this habitat, not all epifauna. The proportion of epifauna increased from 67% at the most downriver station (high mesohaline) to 89% at the oligohaline stations upstream. Biomass was highest in areas with good current structure, keeping substrates free of sediment. Epifaunal suspension feeders appeared limited downriver by predation and possibly turbidity.

Marsh (1973) found 112 epifaunal invertebrates on Zostera in the lower York River (Table III-11). The community was dominated by gastropods, amphipods, and isopods. Most species were suspension feeders or grazed on detritus, algae, and microorganisms on the plant blade. Biomass was highest in summer and fall.

The attached micro- and meiobenthos (Aufwuchs) of the tidal fresh Potomac River were sampled by Spoon (1976). He found 330 species of protozoans and micrometazoans over a 3-year span. Highest numbers occurred in June and July, and the species diversity increased during periods of increased dissolved oxygen. A long-term study by Abbe (1977) on the epifauna in the oligohaline area of the Potomac confirms the observations of previous workers that hydrographic conditions and the salinity regime appear to be the major factors regulating epifaunal growth in this region.

Infaunal benthic organisms have been extensively studied in the Chesapeake Bay, although the earliest surveys were mainly qualitative and directed towards commercially important species such as the oyster or clam (Ryder 1881, Yates 1913, and others). Investigations of benthic assemblages and organism interrelationships have become more common since the 1950's.

Allen (1954) investigated the annual-sediment relationships in a small Maryland estuary, and found the abundance, growth, and survival of six bivalves correlated to varying degrees with sediment type. Pfitzenmeyer (1971) surveyed the Tangier Sound area, and recorded 41 species, mostly infauna. Many of these were characteristic of higher salinities and sandy substrates, and reflect the differences between Tangier Sound hydrography and that of the adjoining Bay mainstem.

Pfitzenmeyer (1970) sampled benthic infauna in a series of stations in the upper Bay oligohaline zone, apparently the first such comprehensive survey of that important area. The majority of the 66 species recorded were soft-bottom deposit-feeders well adapted to a turbid environment. Only three species (Cyathura polita, Leptocheirus plumulosus, and Scolecolepides viridis) were permanent dominants; other species showed seasonal cycles of abundance mediated by temperature or salinity. Average biomass values ranged between 0.4 and 6.4 g dry wgt m^{-2}; population densities and biomass were lowest during the spring months. Another upper Bay study (Pfitzenmeyer 1973) again showed benthic populations to be dominated by a few species: four taxa represented 77% of the specimens collected. Sediment type was more important then depth in determining station similarity, although deep stations were the least diverse.

Boesch (1971, 1972, 1977) investigated the distribution of macrobenthos against the Bay-York River salinity gradient. In general, faunistic changes were gradual and uniform, although certain zones of accelerated change corresponded to particular salinity regimes. The 176 species recorded could be divided into five groups based on origin, extent into estuary, life history, and salinity tolerances (Figure III-12):

- stenohaline marine,
- euryhaline marine,
- euryhaline opportunistic,
- estuarine endemic, and
- freshwater.

Boesch (1973) sampled the polyhaline macrobenthos of the lower James River, and used cluster analysis techniques to identify 16 associations characteristic of certain substrates and seasons. Over 60% of the 93 species exhibited marked periodicity in their occurrence, reflecting seasonal spawning and recruitment. Diversity was highest in sand and muddy-sand sites, and during warmer months.

An investigation of the mesohaline, oligohaline, and freshwater areas of the James River (Diaz 1977) showed a gradual decrease in diversity along the salinity gradient, reaching a minimum in the oligohaline and tidal fresh water areas, then increasing again in the nontidal limnetic zone . This apparently reflected both salinity stress and lack of diverse habitats.

Holland et al. (1977) and Mountford et al. (1977) studied mesohaline communities near Calvert Cliffs, and found depth and sediment type to mediate the structure of these associations. Seasonal depletion of the deepest (9 m) habitat occurred due to summer hypoxia, followed by fall-winter-spring re-colonization.

In the upper Bay, Tropical Storm Agnes had little effect on macrobenthos, save for increased recruitment of the bivalve Rangia cuneata (Pearson and Bender 1973). Siltation apparently

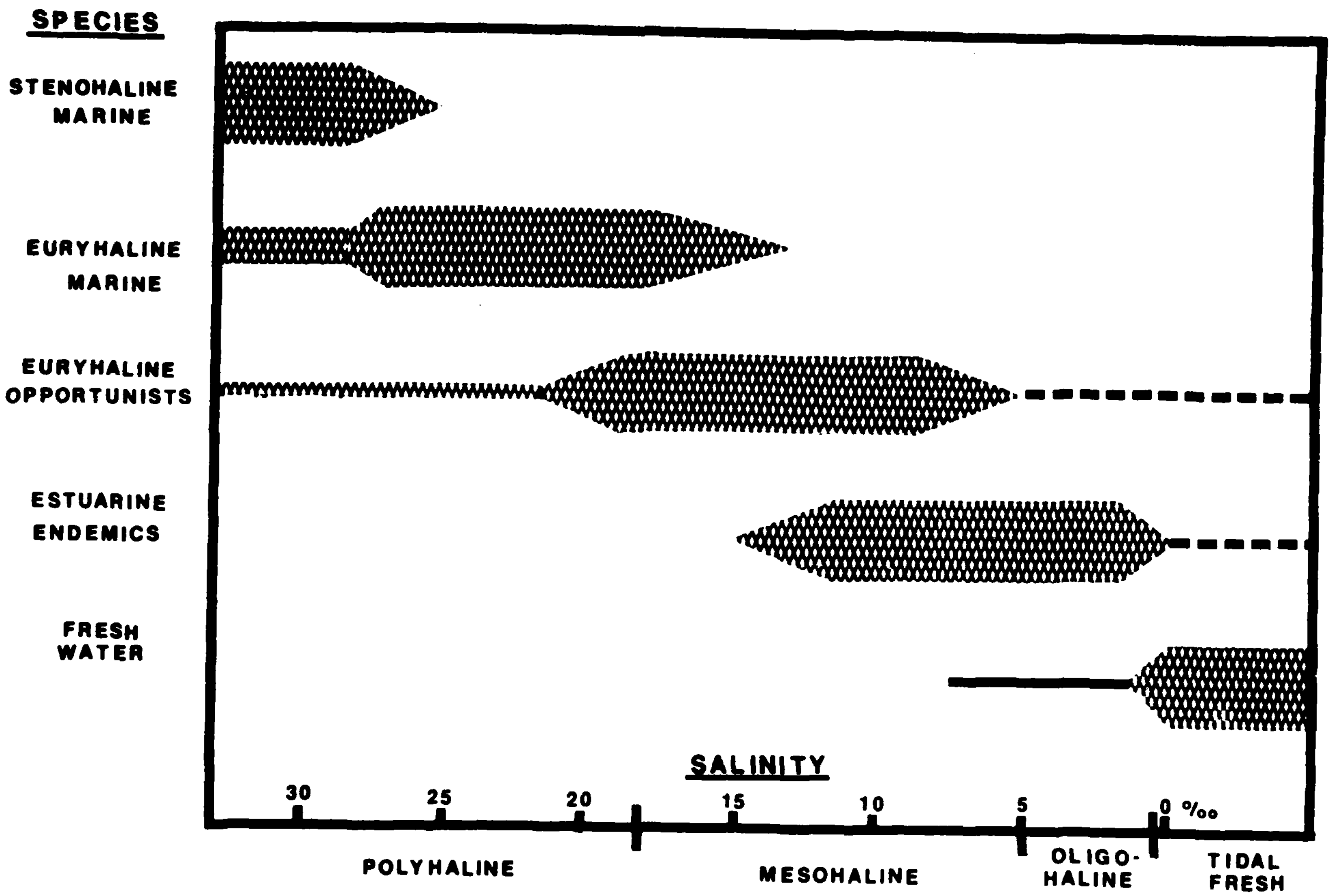

FIGURE III-12 ZONATION OF ORGANISMS ALONG THE ESTUARINE SALINITY GRADIENT.
Source: Boesch 1977

reduced densities of some species, while enhancing others. Boesch et al. (1976) showed that effects of salinity decreases caused by the Agnes freshet on infaunal communities paralleled those reported by Andrews (1973) for epifauna.

The greatest effects were shown in the polyhaline region, particularly in shallow areas. Opportunistic species errupted after the perturbation. Mesohaline infaunal (in contrast to epifauna) communities showed no species eliminated, but did show an incursion of oligohaline species from up-stream.

Numerous workers have emphasized the importance of predation in mediating macrobenthos distributions (Boesch 1971, 1976; Larsen 1974, and others). Virnstein (1977, 1979) used exclosure cages to test effects of fish and crab predation on a macrobenthic community in the lower Bay. Species which were numerical dominants in the natural community showed little change in abundance, as they were well-adapted to escape predators. In contrast, opportunistic species or those subject to heavy predation increased dramatically (Table III-22). Holland et al. (1979) showed similar results from the mesohaline regions of Chesapeake Bay, where species enhanced in the exclosures were shallow-burrowing forms recruiting mainly during colder months when predator densities are low. Neither study found competitive exclusion to be important in mediating benthic distribution or abundance.

Benthic organisms may also serve as habitats for other species. The oyster is or particular importance in Chesapeake Bay; oyster bars shelter densities of organisms an order of magnitude or so greater than the surrounding soft-bottom communities (Wells 1961, Maurer and Watling 1973, Larsen 1974). In addition, productivity can be greatly enhanced (Bahr 1974). This is similar to the effects of submerged aquatic vegetation beds, and emphasized the importance of shelter and substrate stability to benthic communities.

Table III-22

Densities of infauna (per m^2) in exclosures at start of experiment (May 1974), and after two months. (From Virnstein, 1977).

	At start of Experiment	After 2 months
Oligochaete		
Peloscolex gabriellae	2,380	5,760
Polychaetes		
Heteromastus filiformis	560	34,680
Streblospio benedicti	4,840	10,480
Glycinde solitria	260	1,540
Spiochaetopterus oculatus	720	700
Polydora ligni	80	820
Nereis succinea	40	900
Pectinaria gouldii	0	340
Pseudeurytyoe sp.	20	20
Eteone heteropoda	500	100
Bivalves		
Mulenia lateralis	20	8,820
Mya arenaria	660	400
Lyonsia hyalina	0	320
Phoronid		
Phoronis psammophila	160	880
Total individuals	11,480	68,840

In summary, it can be seen that the seasonal and spatial distribution of benthos is primarily mediated by physical factors of the environment (chiefly salinity, substrate type, dissolved oxygen, and temperature). In addition, predators exert a controlling effect on the population densities of many Chesapeake Bay benthic organisms. Low flow can be expected to alter not only salinity (with implications for distribution of benthic species), but also turbidity, sedimentation and circulation. Reduction in summer stratification may reduce summer anoxia in many areas; however, a decrease of saline inflow at depth can have potential adverse affects on the many species which depend on this mechanism to penetrate or maintain themselves within the estuary.

6. Fish

The fish of the Chesapeake Bay region exhibit a wide variety of habitat requirements, many of which are keyed to lifestyle, season or physiology within a given species. For example, spawning behavior ranges from ocean spawners such as spot (Leiostomus) to fresh water spawners such as striped bass. Some Bay fish such as menhaden are seasonal, while others use various parts of the Bay throughout the year. Since comprehensive studies of fish distribution are somewhat limited in comparison with other key organisms (i.e. SAV, benthos, waterfowl), this report also relies on information on commercial and sport landings where they exist. Common names for fish species used here follow the American Fisheries Society List of Common and Scientific Names.

Fishing is the consumptive resource use for which Chesapeake Bay is most well known. None of the states bordering Chesapeake Bay or its tidal tributaries require a recreational fishing license in tidal water. Therefore, accurate information on the number of sport fishermen or the number of each species landed is not available. Without data of this type, fish populations by species cannot be accurately determined. However, in the absence of adequate landing data, sampling surveys have been attempted

(Shearer, Ritchie and Frisbie 1960; Richards 1962; Spier, Weinrich and Evely 1977). These surveys provide the best available estimates of the species which are most important to the sport fishery.

Speir et al. (1977) found that five species of finfish (striped bass, bluefish, white perch, croaker and spot) were each caught in quantities greater than the commercial catch in the Maryland portion of the Chesapeake Bay. The U.S. Department of Commerce, National Marine Fisheries Service (1978) estimated that 1,784,000 persons from Maryland, Virginia, and the District of Columbia caught 67,444,000 pounds of finfish and 12,677,000 pounds of shellfish and crustaceans in 1974. Table III-23 illustrates the relative proportion of the total fish landings from Chesapeake Bay which were contributed by the sports and commercial fisheries.

Figure III-13, a reproduction of Dovel's (1971) classic diagram, shows the importance of the common estuarine nursery area. The low salinity common nursery area is located in one of the regions expected to experience a major shift in salinity regime (see Figure III-5). Therefore the early life histories of fishes as diverse as ocean spawners and fresh water fishes are tied to the fate of one relatively small area.

Early life history information is available in a variety of comprehensive volumes, the most important of which is the six volume set, The Development of Fishes of the Mid-Atlantic Bight (1978 — various editors for different volumes). Other summaries of more restricted geographic range include Dovel (1967 and 1971), Lippson and Moran (1974), Hogue et al. (1976) and Wang and Kernehan (1979). Effects of dredge spoil and sedimentation on early life stages were investigated by Auld and Schubel (1974) and Schubel et al. (1974). Striped bass spawning was found to be most intensive in the C & D canal by Dovel and Edmonds (1971) and Johnson and Koo (1975). Life history information for individual species is given as referenced below:

Table III-23

Relative Contributions of the Sport and Commercial Fisheries in Chesapeake Bay - 1974.

	Finfish[1] in Pounds	Shellfish in Pounds	Total Catch	Percent of Total
Sport[2] Fisheries	67,444,000	12,677,000	80,121,000	38.8
Commercial[3] Fisheries	35,879,500	90,563,600	126,443,100	61.2
Total Catch	103,323,500	103,240,600	206,564,100	100
Percent	50	50		

1. except Menhaden and fish for reduciton
2. source, National Marine Fisheries Service, Fisheries of the United States, 1978
3. source, National Marine Fisheries Service, Fisheries of the United States, 1974

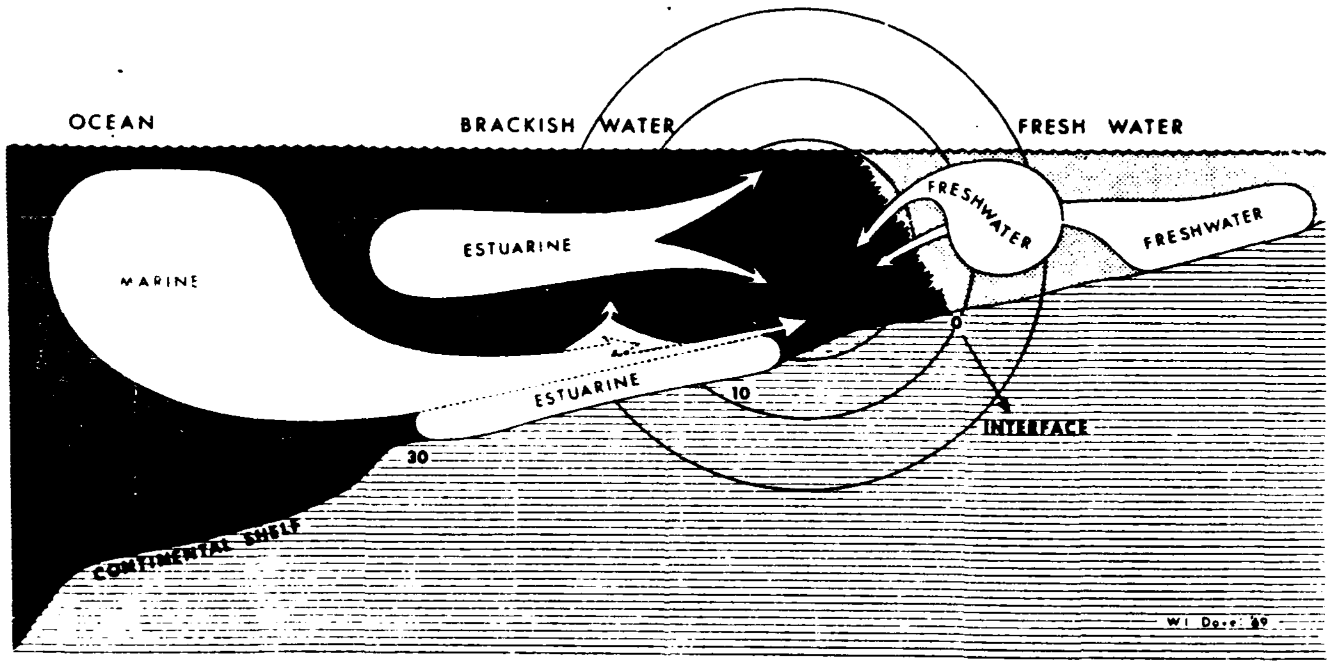

Figure III-13 SCHEMATIC DIAGRAM OF MOVEMENTS OF ESTUARINE-DEPENDENT FISH LARVAE AND JUVENILES TOWARD A COMMON LOW SALINITY NURSERY AREA

Numbers represent approximate salinity in parts per thousand (‰)

Source: Dovel, 1969

- Muncy (1962) - yellow perch
- Mansueti (1964) - white perch
- Merriner (1976) - weakfish
- Joseph et al. (1964) & Silverman (1979) - black drum
- Wallace (1940), Haven (1957) - Atlantic Croaker
- Norcross et al. (1974) and Kendall and Walford (1979) - bluefish
- Dovel et al (1969) - hogchoaker
- Lewis (1966) - Atlantic menhaden
- Mansueti (1962) - hickory shad
- Marcy (1972) - American shad
- Chambers et al. (1976) - blueback herring
- Massmann et al. (1962) - menhaden

Colton et al. (1979) presented a graphic summary of timing and location of spawning for marine spawners in the mid-Atlantic bight.

Distribution of fish in an estuary reflects salinity tolerance and other factors. Distribution data is essential for mapping, but the data must be interpreted by information gained from a study of salinity tolerances.

Distribution studies with respect to salinity and other variables were conducted by Scott and Boon (1973), Environmental Services Department VEPCO (1976), Raney and Massmann (1953), Schwartz (1960), Kemp and Bayless (1964), Dallberg and Odum (1970), Pearson and Ward (1972), Turner and Chadwick (1972), McErlean et al. (1973), Thomas and Smith (1973), Weinstein (1979), Kaufman et al. (1980).

Salinity preferences or salinity limits to survival or distribution of finfish have been investigated by Fritz and Garside (1974) for killifishes and Bishai (1961) for larval fishes. Kendall and Schwartz (1968) studied temperature and salinity tolerance in white catfish, Tagatz (1961) for shad and striped bass, Chittenden (1973) for shad, Lewis and Hetter (1968) for menhaden, and Schwartz (1964) for 29 Chesapeake and Delaware Bay species. Weinstein (1979) studied the distribution of juvenile fishes along gradients of salinity, temperature and substrate characteristics.

Food and feeding pattern studies are necessary to the development of trophic interaction models. Feeding studies have generally been of two types; (1) theoretical attempts to define characteristic ingestion values, and (2) species specific food and growth rate studies.

Theoretical studies: Few theoretical studies have been performed specifically on the Chesapeake Bay region on Fish. For example, Phillips (1969), Kerr (1971), and Paloheimo and Dickie (1966 a & b) looked at other published studies to define general metabolic requirements and rations for fishes. Wiley et al. (1972) used a trophic efficiency factor to estimate finfish production in Chesapeake Bay. Eggers et al. (1978) examined changes from a detritus based food chain to a zooplankton grazing based food chain as a result of environmental changes. Saila (1975) reviewed and described simple models relating primary production to finfish production.

Species specific food and growth rate studies: Species specific studies tend to concentrate on those species with commercial utility. The Atlantic menhaden passes through distinct dietary changes as a result of a physiological metamorphosis. These changes were investigated by June and Carlson (1971), Durbin and Durbin (1975), Taylor (1951), and Jefferies(1975). Durbin (unpub. a) also conducted a thorough study of feeding rates and productivity of adult menhaden. Multispecies food and feeding studies were conducted by Peters and Kjelson (1975), who looked at menhaden, spot, pinfish, and southern flounder. Chao and Musick (1977) examined food habitat of ten juvenile sciaenid fishes from lower Chesapeake Bay. Strickney et al. (1975) also studied food habits of sciaenids.

Striped bass feeding has been investigated by McHugh (1967), Markle and Grant (1970), Miller (1978), Seitzler et al. (1978) and Wiley et al. (1978).

Burbidge (1974) described feeding habits of blueback herring, and Massmann (1963) the feeding of shad. Makashima and Leggett (1978) determined rations for yellow perch, and Mayers and Muncy (1962) for chain pickerel.

Very important summaries of types of food organisms of many endemic fish species are provided by Homer and Boynton (1978), Lippson et al. (1979), and Hildebrand an Schroeder (1928) which, despite its age and occasional inaccuraces, remains the standard reference book for Chesapeake Bay fishes.

Energy and food relationships were investigated by Darnell and Wissing (1975). Oxygen consumption, rations, and activity relationships were studied by Ware (1978), Lawrence (1975), Wohlschlag et al. (1968), Durbin (1976) and summarized by Carlander (1977) for many centrachids. Oviatt et al. (1972), and Durbin (1976) examined menhaden energetics in detail. Then Oviatt and Kremer (1977) studied feeding and metabolism of the butterfish.

Finfish population sizes are a bsic concern in Chesapeake Bay. Population size can be considered in numbers of organisms (population), weight or organisms (biomass), or weight density in a given unit of area (also called biomass). Of these, biomass is often considered the most ecologically useful parameter.

Biomass determinations for Chesapeake Bay and tributaries are sparse. Carter (1973) provides a summary which is limited to the upper Bay and Susquehanna River. Several studies in the marine environment have related gross finfish production to nutrient loadings or primary productivity but were to general to be useful this study.

Population estimates are frequently made from landings data and these data are common. In addition to the National Marine Fisheries Service annual Statistical Digest giving landings by species and by state, ten localized studies are available within the study area giving landings and sometimes catch per unit effort over a range of years for eith major species.

Data on age and growth of fishes is the most abundant type of information on fishes, with over 15 title giving growth equations for individual species. There is some type of growth rate information on every important finfish species in Chesapeake Bay.

Ulanowicz and co-workers have investigated correlative effects of physical factors with commercial fish and shellfish landings (Ulanowicz et al. 1980) and in more detail with respect to oyster harvest (Ulanowitz et al. 1980). These studies have shown that more than 50 percent of the catch variation in most species can be explained by annual variations in temperature, salinity and precipitation. This suggests that economic effects such as market-value may be less important than previously thought, and that catch data can be used as a useful indicator of ecosystem productivity, at least to a limited degree for most fish species. Salinity itself was a minor variable, accounting for less than 15 percent of the variation, although other variables (i.e. dry vs. rainy days) are also related to salinity and river flow. For oysters, however, 21 percent of the variation was positively correlated with cumulative excess salinity (>16.5 ‰).

Low flow will affect fish mainly through the compression of suitable nursery areas. Second-order affects can also be expected due to changes in productivity of zooplankton and benthic organisms.

7. Wildlife

Wildlife associated with the Chesapeake Bay ecosystem consists of reptiles , amphibians, mammals, marine birds and waterfowl. In this subsection, we have limited the discussion to waterfowl due to the fact that only these species were included as "study species". This should not be construed as minimizing the importance of other, less-studied or less salinity sensitive species. Rare or uncommon species are discussed briefly in Section V.-E.

The states of Maryland and Virginia, in cooperation with the U.S. Fish and Wildlife Service, survey the wintering waterfowl population in those states in January. The following is a list of the waterfowl found in the Chesapeake Bay portions of those states during the surveys.

A. PUDDLE DUCKS

- Mallard
- Black duck
- Gadwall
- Baldpate
- Blue-winged teal
- Shoveler
- Pintail
- Wood duck
- Green-winged teal

B. DIVING DUCKS

- Redhead
- Canvasback
- Scaup
- Ringneck
- Ruddy
- Bufflehead
- Goldeneye
- Merganser

C. SEA DUCKS

- Old Squaw
- Scoter

D. GEESE, SWANS, AND COOTS

- Snow goose
- Blue goose
- Canada goose
- Brant
- Coot
- Whistling swan

Table III-24 lists the number of individuals of each species found in the 1980 Maryland and Virginia mid-winter waterfowl surveys. The most abundant wintering waterfowl species in the Chesapeake Bay is ths Canada goose. In 1980 this species comprised more than 60% of all the waterfowl individuals in the Bay area. Most of these birds were found in Maryland. The two most abundant puddle ducks were the mallard and black duck, while the canvasback and scaup were the most abundant diving ducks.

TABLE III-24

Maryland and Virginia Mid-Winter Waterfowl Counts for 1980 (Chesapeake Bay Tidal Waters Only)

SPECIES	MARYLAND ABUNDANCE[1]	VIRGINIA ABUNDANCE[2]
Mallard	28,400	31,000
Black duck	17,100	21,400
Gadwall	800	200
Baldpate	1,800	3,400
Green-winged teal	300	1,500
Blue-winged teal	0	0
Shoveler	100	400
Pintail	500	2,800
Wood duck	0	100
TOTAL PUDDLE DUCKS	49,000	60,700
Redhead	200	8,100
Canvasback	29,100	18,600
Scaup	3,000	20,300
Ringneck	300	3,800
Goldeneye	2,300	1,700
Bufflehead	3,900	11,100
Ruddy	3,400	10,800
Merganser	700	3,800
TOTAL DIVING DUCKS	42,900	78,100
Old Squaw	2,200	2,700
Scoter	10,500	4,600
TOTAL SEA DUCKS	12,700	7,400
Brant	0	800
Snow Goose	2,700	25
Blue Goose	700	200
Canada Goose	479,800	49,200
TOTAL GEESE	483,200	50,200

continued.

TABLE III-24

Page 2

SPECIES	MARYLAND ABUNDANCE	VIRGINIA ABUNDANCE
Coot	4,200	4,700
Whistling Swan	29,500	4,200
GRAND TOTAL	621,500	205,300

1. Calculated from unpublished data, Maryland Wildlife Administration.

2 Calculated and rounded from unpublished data, Virginia Fish and Game Commission.

Canvasbacks have received particular attention in the Chesapeake Bay because of their population decline nationally and locally, and their importance as a harvested species. The Chesapeake Bay is probably the most important area for canvasbacks within the Atlantic flyway. There are indications that canvasbacks have shifted their diets from predominantly plant to primarily animal, possibly as a result of the decline in submerged aquatic vegetation in the Bay (Stevenson & Confer 1978; Perry and Uhler 1976). Perry (unpublished) has shown that canvasbacks in the Maryland part of Chesapeake Bay have moved from areas where submerged aquatic vegetation was abundant to areas in the Bay where the bivalve *Rangia cuneata* has become abundant.

The diet of many waterfowl species can vary depending upon what is available. Perry and Uhler (unpublished) found 133 food items in the gizzards of 9 species of waterfowl (116 individuals) from freshwater areas of the James River. *Cyperus* spp. *Leersia oryzoides*, and *Polyganum* spp. were predominant plant species. Rawl (in-press) examined the gizzards of 1,179 waterfowl and found *Potamogeton perfoliatus*, *Ruppia maritima*, *Mya arenaria* and *Macoma balthica* to be the most prevalent plant and animal food items. Steward (1962) reported the food items taken by waterfowl in the upper Bay. Important food items included such plant species as *Ruppia maritima* (widgeon grass) and *Potamogeton perfoliatus* (claspingleaf pondweed), emergent plants such *Polygonum* spp, and animal species such as *Macoma balthica* and *Mulinia lateralis*. Some waterfowl, such as the redhead, seem more dependent upon certain types of food. The decline of submerged aquatic vegetation in the Bay, an important food source for the redhead, could be affecting the distribution and abundance of that species in the Chesapeake Bay.

Waterfowl breeding populations on wildlife management areas in Maryland are surveyed by the Maryland Department of Natural Resources. Four species (Mallard, Black duck, Gadwall, and Blue-winged teal) were reported . A fifth species, the wood duck, also nests in the Chesapeake Bay region. Of these ducks, only the black duck is present in large numbers throughout the year. The wood duck is a common breeder in the Bay region but is rare as a winter resident (Stewart 1962). Stotts and Davis (1960, studying black duck breeding on Kent Island, found that most of the breeding birds there nested in wooded uplands. However, black ducks nest in a variety of habitats in the Chesapeake Bay region (Stewart 1962).

The Chesapeake Bay is well-known for its waterfowl hunting. During the 1977 and 1978 hunting seasons the mallard was the species most frequently taken, accounting for 23% to 30% of the kill in Virginia, and 33% to 38% of the kill in Maryland (Table III-25). In Maryland, black ducks and scaup comprise a large percentage of the kill, while in Viriginа black duck, scaup, and wood duck were taken often. In 1978, however, the percent-kill of lesser scaup was very low in both states. The total duck kill in Maryland in 1978 was roughly 183,800 birds, while in Virginia the total kill was 133,100. Total duck kill for the Chesapeake Bay was 316,900 ducks.

Canada geese were heavily harvested in Maryland, with a kill of 118,700 birds. In Virginia the 1978 Canada goose harvest was 18,700 birds. Total Canada goose harvest in the Chesapeake Bay was 137,400 birds.

Wildlife will not be immediately affected by low flow, since most are not physiologically dependent on specific salinity regimes. As shifts in SAV and EAV occur, distribution of waterfowl and other wildlife can be expected to change also.

TABLE III-25

Percentage composition of the 1977 and 1978 Hunting Kill for Maryland and Virginia

SPECIES	PERCENTAGE OF KILL IN EACH STATE			
	Maryland		Virginia	
	1977	1978	1977	1978
Mallard	33.3	38.8	23.5	30.3
Black Duck	12.9	24.7	8.4	14.1
Gadwall	0.8	1.8	4.8	5.6
Baldpate	2.2	4.1	6.0	6.0
Green-winged Teal	2.2	10.4	5.0	5.1
Blue-winged Teal	0.1	1.0	1.0	3.7
Shoveler	0.1	1.0	0.6	0.1
Pintail	2.2	1.8	2.4	1.5
Wood Duck	0.5	4.9	21.6	17.4
Redhead	0.0	0.0	0.0	0.0
Canvasback	0.0	0.0	0.0	0.0
Greater Scaup	3.3	0.2	0.8	0.4
Lesser Scaup	20.6	0.2	10.5	0.3
Ringneck	0.1	0.2	4.3	6.0
Goldeneye	0.7	2.0	2.1	1.3
Bufflehead	3.9	2.6	4.0	3.1
Ruddy	0.7	0.2	0.2	0.6
Old Squaw	3.8	1.8	0.8	0.0
Scoters	6.2	1.1	0.4	0.0
Hooded Mergansers	0.3	0.0	1.8	2.3
Other Mergansers	0.0	0.0	0.5	0.0
Other ducks	0.0	0.0	0.0	0.0
TOTAL RETRIEVED KILL (number of ducks)	74,995	183,772	130,077	133,140

Source: Administrative report, U.S. F.W.S., 21 June 1979.

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IV. DEVELOPMENT OF BIOTA ASSESSMENT METHODOLOGY

As stated in earlier chapters, the Biota Assessment is divided into two distinct phases. Phase I is directed at evolving methodologies for determining effects of salinity changes on Chesapeake Bay biota. During Phase II these methodologies will be applied to several normal and low flow scenarios (see Chapter II). Due to the complexity of this state-of-the-art process, it is inevitable that refinement and modifications of the methodology will occur in Phase II.

Beginning with this chapter and continuing through Chapters V and VI, we discuss the development and implementation of the Biota Assessment Methodology developed in Phase I, beginning with a discussion of alternative methodological strategies (Chapter IV-A) and the reasons for the selected methodology. This is followed by an elucidation of the steps taken in developing the selected methodology beginning with establishment of an environmental baseline and following through discussions of fluctuations from the baseline, and habitat classification (Chapter IV.B-E), the selection of study species and their distribution and mapping (Chapter V), and development of conceptual and mathematical models (Chapter VI). Chapter VII then discusses the actual planned use of these various methodological tools during Phase II illustrating this use with a hypothetical test case.

A. ALTERNATIVE METHODOLOGICAL APPROACHES TO BIOTA ASSESSMENT

The purpose of evolving the biota assessment methodology in this report is to arrive at a method which can be used to predict (in a quantifiable manner) the effects of low flows (mainly as manifested by salinity) on Chesapeake Bay organisms. To this end the resulting methodology must:

- distinguish between several drought scenarios

- be sensitive to small (possibly as small as 2 - 3 ‰) salinity variations
- be represented by a "reasonable" number of organisms
- take into account the dynamic interactions between organisms
- be quantifiable in relation to some standard.

Of these criteria, the last appears simple, but is perhaps the most difficult, both conceptually and philosophically. In the remainder of this section, we will first address the problem of setting such a standard, and will then show other aspects of alternative methodologies.

A standard or baseline must be set before any type of comparison can be made. In the Chesapeake Bay, an obvious first choice for an environmental baseline is a condition in which the Bay functions as a well-balanced, healthy and productive dynamic system. The three methodological choices which this implies are:

- fix an absolute standard which characterizes a "healthy and productive" Bay
- fix an arbitrary standard from which improvement or degradation can be measured
- fix a relative standard which is partially arbitrary, but which is keyed to conditions which are at least "acceptable" if not fully "healthy and productive"

The first choice is the most desirable in that it would fix an upper limit which "impacts" would then lower. To determine the feasibility of fixing such an absolute standard, a conference of Bay scientists and management specialists was held in November 1979 (see Chapter II). A concensus of scientists present felt that definition of one standard of Bay "health" or "productivity" was not possible in an absolute sense. Additionally, it was felt that use of a totally arbitrary standard would add little or nothing to the scientific validity of impact assessment. During the conference, the attendees and WESTECH staff agreed that the optimal approach was to set the best possible relative standard, based on criteria of "acceptable" health and productivity.

This led to the concept of defining some form of baseline or base period which represents average physical and biological conditions. With the general methodological path of a "relative baseline approach" selected, WESTECH then proceeded simultaneously with defining these baselines (see section IV-B) and developing methodologies for assessment of differences between the baseline and a given scenario.

Three types of approaches are popularly used by scientists and planners to measure change:

- professional judgement approach
- index approach
- simulation approach

Each of these approaches has strengths and weaknesses. The first usually relies on some variant of the Delphi technique in which a panel of experts give their best professional judgement (in effect "voting") on the issue (i.e. amount and significance of each impact). Used alone, this approach works best on narrowly defined questions where a small group of top experts can be easily assembled. The second approach is based on measuring individual changes which are somehow combined to form an overall index or series of indices. This approach works best when the change can be organized and quantified geographically or chronologically. The third method involves the creation of some form of "model" which may be a theoretical conceptualization or a detailed mathematical simulation. This approach works best when the laws of interaction within the system are well known and the system itself is relatively simple.

The three approaches each contain serious problems when applied to a complex estuarine system such as Chesapeake Bay. WESTECH's choice of methodology involved selecting the most workable approach as a working methodology, but attempting to combine some of the strengths of the other two methods. The index approach was selected as the most feasible way of judging biological changes in a realistic and unbiased manner.

The professional judgement approach was judged to be unweildy and to lead to possible bias. The large number of organisms and fields of study on the Bay would have required the assembly of a large committee of specialists who would need to "vote" on each impact change. The concept of maintaining professional judgement input, however, was determined to be important. Therefore, WESTECH and the Corps of Engineers selected both WESTECH's interdisciplinary anchor team and the Corp's Steering Committee to review all major methodological steps in the development of indices to measure biological change.

The simulation approach was judged to be too complex to perform in total. An example of a total simulation would be to mathematically predict the behaviour of all major Bay organisms in a dynamic model simultaneously. The power of simulation for both conceptual understanding and for analysis of ecosystem dynamics, however, was felt to be a vital supplement to knowledge gained from the index method. Therefore, an approach was developed which focuses on the index method but which also utilizes professional judgement of experienced scientists and which has available the tool of conceptual and simulation models to enhance understanding and reliability of the indices.

Specifically, the index method developed relies on:

- definition of key species
- elucidation of organism tolerances for salinity and other major parameters for these species
- use of the tolerance information to define and map organism distribution
- comparison of the amount of organism "habitat" available under various flow scenarios
- numerical comparison of habitat availability changes for key organisms (see Impact Ratios discussed in Chapter VII)
- using conceptual and/or simulation models as a tool to enhance the meaning and implications of the indices calculated

As mentioned above, the index also assumes some form of environmental baseline. The development of the components of such a baseline are discussed in the following section. In the remainder of this chapter and in Chapter V, we first put the baseline in perspective by briefly examining known fluctuations from the baseline, followed by explanations of the processes of habitat classification, defining key species, cataloging organisms tolerance and mapping organism distribution. Chapter VI then describes development of the conceptual and simulation models, one or both of which must be used as a tool to place the indices in perspective. By laying this groundwork in Chapters IV, V and VI, we set the stage for the discussions of the actual form of the indices (in Chapter VII) which will be used to assess impact in Phase II of the Biota Assessment.

B. DEFINITION OF ECOLOGICAL BASELINES

An ecological baseline for the Chesapeake Bay has physical, chemical and biological components. It is preferable to standardize assumptions about each component as much as possible, recognizing the unlikelyhood of complete standardization. Setting a baseline based on actual conditions also implies selection of a time or time period in which those conditions held and over which measurements of the conditions were reported. It may also be necessary to consider the geographical homogeneity of the baseline data. Below are discussed the selection of physical, chemical and biological baselines in terms of time periods, data requirements and, when necessary, geographical segmentation.

1. Physical (Base Year)

For physical data, in particular salinity, base data was found to be available as seasonal averages. These data were aggregated in longterm mean values in some cases; however, the choice was made to use a representative year rather than a longterm mean value.

In order to understand the rationale behind this selection, certain related concepts must be defined. Figure I-3 portrays the average (mean) and extreme (range) of 30 years of recorded freshwater inflow to the Chesapeake Bay. Figure IV-1 shows monthly variation of inflow. The shaded border indicates a wide range of variation of freshwater inflow into the estuary. Since inflow data are graphed on a logarithmic scale, the actual variations from year to year are more dramatic than the figure indicates visually. A second important feature is the approximately sinusoidal curve of the mean monthly inflow, which peaks in March and April, reaching its low point in September. Following this pattern, Water years are defined as the period of time from October 1 to September 30 of the following calendar year. The U.S. Army Corps of Engineers uses the water year as a base for the Chesapeake Bay hydraulic model; which will ultimately provide salinity data for baseline conditions in Phase II of the Biota Assessment. However, the Corps modifies the water year from a continuous fuction to an "average weekly flow" step function with the step duration being seven (prototype) days. This has the effect of eliminating short-tem transient phenomenon such as freshets.

If all the monthly means for one year are averaged into a mean annual stream flow, the result would be as shown in Figure I-3. The mid-point of flow for the period 1950 - 1979 is about 75,000 cubic feed per second (cfs). The period closest to this median point are the water years of 1960 - 1962. The second year of of this period was chosen for use as an average flow year for Phase I of the Biota Assessment on the assumption that the second in a series of "average" years would be the most free from historical effects of a previous anomalous flow. For mapping purposes, Water year 1961 (October 1960 - September 1961) salinities are used to define "average salinity" conditions for the purposes of this Phase I report. Salinity base maps have been produced for available seasonal salinities during this Water year. The maps are part of the Map Atlas which accompanies this report.

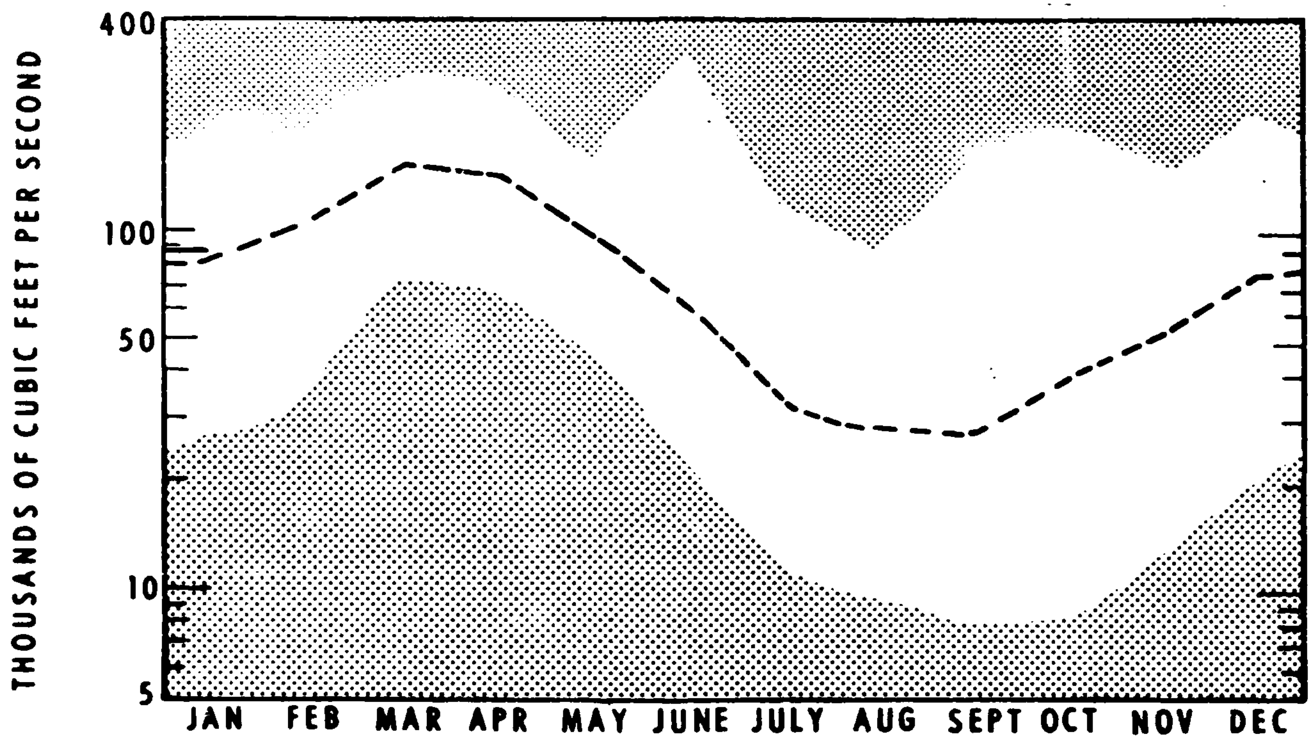

Figure IV-1. MONTHLY MEAN STREAMFLOW IN CHESAPEAKE BAY

Unshaded area indicates range between highest and lowest values of the 30 year record

Source: U.S. Dept. of Interior, Geologic Survey, monthly streamflow summary

Using both the Chesapeake Bay Salinity Atlas (Stroup and Lynn 1963) and the Chesapeake Bay Oceanographic Data Base (Maryland Tidewater Administration, Borman 1974), isohalines were plotted for the 1960 - 1961 Water year at depths of 0, 10, and 20 feet (approximately 0, 3 and 6 meters) for the following time periods:

Spring	March - May, 1961
Summer	June - August, 1961
Autumn	September - November, 1961

Winter isohalines (1960 - 1961) were found not to be available for the Base Year from the Salinity Atlas. Where a species distribution in winter was to be mapped, the "Winter Average" isohalines from Stroup and Lynn (1963) were used, or in some areas, late fall salinity distributions were substituted for missing winter salinity values.

Water years 1964 - 1966 are historically low flow years. Distribution of organisms have been mapped in Phase I according to the salinities measured in the appropriate season of the Water year 1961, and other factors (see Chapter V). It should be noted that the distributions thus mapped are expected to be "typical" but not all inclusive of the organisms reported distributions. Long-term salinity averages (20 year averages which are available from Chesapeake Bay Institute Data) were not used because it was felt that long-term averaging would tend to suppress important variations in salinity which are present in "real" years. Several departures from observed conditions should be noted here for the drought hydrography (Low Flow) which has been tested on the Corps hydraulic model. These will to some extent influence the interpretation of biolgical effects of this data.

1. As mentioned, the continuous inflow has been converted to a step function. This reduces the effects of "freshets" and other very short-term phenomena, although seasonal averages will be accurate.

2. The effects of three dams, not yet constructed, are being simulated in the 60's drought hydrograph. These dams are:
   - Bloomington - on the Potomac River
   - Raystown - on the Susquehanna River
   - Gathright - on the James River.

   It is to be expected that the use of these dams in drought hydrograph simulation will have an "evening" effect on flows. Low flows in the simulation will not be as low as those during the 1960's.

3. Liquid inflow from wastewater treatment plants will be added to the model, as fresh water, at eight inflow points during the base test (1960's) and 12 inflow points during the futures test (2020). Wastewater discharges will be simulated by steady outflow totaling 744 CFS in the 1960's and 1,717 CFS in the year 2020 test. Only the Blue Plains Wastewater Treatment Plant will be operated as a variable outflow according to a schedule developed by the Corps of Engineers Waterway Experiment Station and tabulated in the Testing Program Low Freshwater Test Description (1979 unpub. MS.).

Thus, it is expected that the average hydrograph tests to be used in Phase II of the Biota Assessment will be similar in nature but not identical to seasonally averaged data used in the Phase I base period. The Phase I base data; however, should provide relatively close seasonal averages which will be used for comparative purposes.

2. Salinity Distributions and Inflow

The difference in freshwater inflow between the base year and a drought year for selected inflow points is shown in Table IV-1. Each tributary draws from a different watershed. Although the 1960's drought was generalized throughout the east coast, the Potomac River showed considerably greater reduction in fresh-

TABLE IV-1.

Annual Mean Freshwater Inflow in Cubic Feet Per Second to Chesapeake Bay from Selected Tributaries 1961 and 1965.

SOURCE	Water Year 1961	Water Year 1965	% of Base Year Flow
Susquehanna	36,800	22,300	60.6%
Potomac	15,100	10,300	68.2%
James	12,300	7,400	60.2%
Total for Bay	78,000	49,000	62.8%

Source: U.S. Geological Survey 1979

water inflow than most other rivers. Thus, the movement of the isohalines up the rivers and mainstem of the Bay is not necessarily uniform between tributaries. Additonally, each river basin may have its own separate year of lowest recorded flow.

For the Potomac River (during the period of 1951 - 1979) the lowest flow was in 1969. Table IV-2 shows the salinity values at five locations along the river for four months of the year, comparing 1969 and 1970 (data from Lippson et al. 1979). Some observations which can be made from Table IV-2 are that:

- the greatest differences between the years shown is larger than the greatest seasonal variation,
- the greatest absolute increase in salinity is downstream from the freshwater-salinity interface (0.5 ‰: see last column), and
- salinity patterns were more stable in the drought year (1960) than in the normal flow year (1970).

Thus, during the drought period, salinities were consistently higher, even during seasons of nomally low salinity.

The ratio of salinity differences in the Potomac River between the low flow and average flow years is about 3.6:1. It may well be that when the salinity patterns are obtained from the Chesapeake Bay hydraulic model, the variations between average and low flow scenarios will be larger than the typical seasonal variations in certain areas.

Drought changes in salinity of the same order of magnitude as seasonal changes may cause small, non-catastrophic biotic changes. Quite sensitive measures may be required to detect such small changes. The use of long term (20 years) average salinity values are available for the Bay and some tributaries (Stroup and Lynn 1963, Lippson 1973). This would provide better areal and seasonal coverage but contains high and low flow years averaged in. The result of using such averages for a baseline would be to reduce the sensitivity of the analysis by including drought data in the baseline. The degree to which 1961 salinity data has

TABLE IV-2.

Surface Salinities in the Potomac Estuary in a Low Flow and A Normal Flow Year at Selected Locations Along the Axis.

Location Name	Nautical Miles From Mouth	February		[illegible]		August		November		Greatest Seasonal Difference In One Year ‰	Greatest Difference Between Years In One Season
		1969	1970	1969	1970	1969	1970	1969	1970		
Piney Point	14	17	14	16	9	14	11	15	13	5	7
Morgantown	40	9	6	10	3	7	8	10	3	5	7
Maryland Point	55	4	2	4	4	3	4	7	2	4	5
Indian Head	75	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.5	0.4	0.4

(Source: Data from Lippson et al. 1979).

All values expressed in parts per thousand, (‰)

influenced the salinity averages is uncertain. There is neither a synoptic tabulation nor an atlas of salinities available for the low flow year. Thus indirect methods must be used to estimate expected relative magnitudes of salinity change during low flow periods.

Pritchard's (1950) Delaware River estuary study indicated that the changes in salinity resulting from increased river flow were attenuated at both ends of the estuarine salinity gradient and most drastic in the middle reaches. This would seem to conflict with the salinity shifts observed in the main Bay (Chapter III, Figure III-5). However, the ratio of inflow to tidal volume is considerably different in a narrow river estuary than it is in the main Bay where the freshwater inflow can spread over the saltier water in a thin sheet. It is the relationship of inflow to tidal volume which partially determines stratification and the longitudinal velocity profile (Dyer 1973). The available evidence indicates that a different pattern of salinity change consequent to reduction of freshwater inflow may be observed in the main Bay and wider tributaries than may be observed in the narrower tributaries. Pritchard's (cited in Andrews 1964) study of effects of releases from Salem Church Dam on the Rappahannock River salinities indicates that moderate supplementary releases of freshwater produce the greatest change in salinity per unit volume of flow (Figure IV-2). It would appear that too rapid a release may increase stratification instead of dilution.

3. Bay Segmentation

The geographic limits of the study are the Chesapeake Bay and tributaries to the head of the tide, and seaward to a line connecting Cape Charles and Cape Henry at the point where the distances between the two capes is least. Figure IV-3 illustrates the geographical limits of the study. Thirteen Bay segments have been defined for use with the Chesapeake Bay Ecosystem Model (see Chapter VI); however, these were not utilized for Phase I, being a part of the impact assessment to be conducted in Phase II (see Section VIII-B).

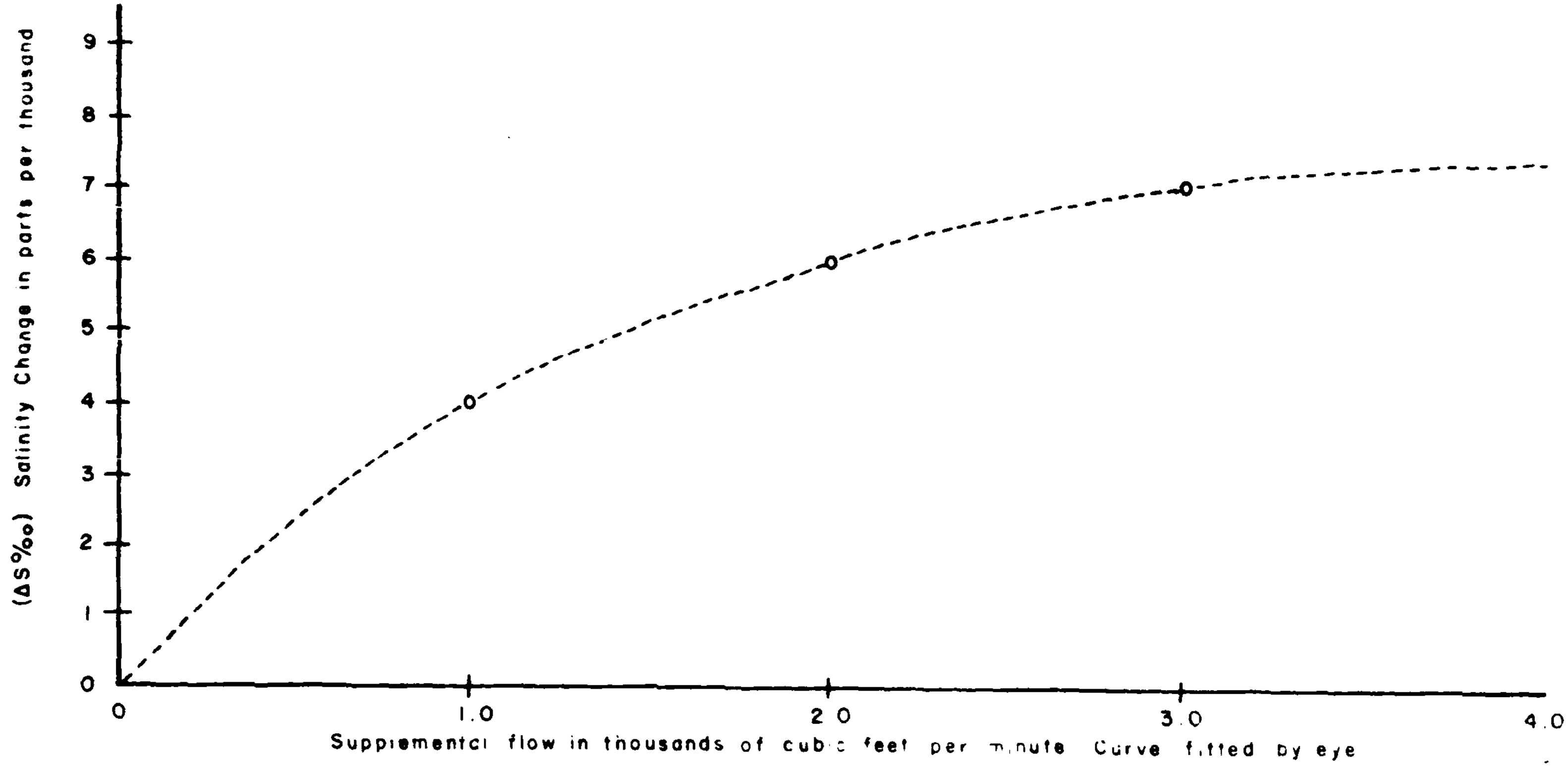

Figure IV-2 **CHANGE IN SALINITY IN RELATION TO SUPPLEMENTED FLOW IN THE RAPPAHANNOCK RIVER**

Source: Pritchard, 1955 cited in J.D. Andrews, 1964

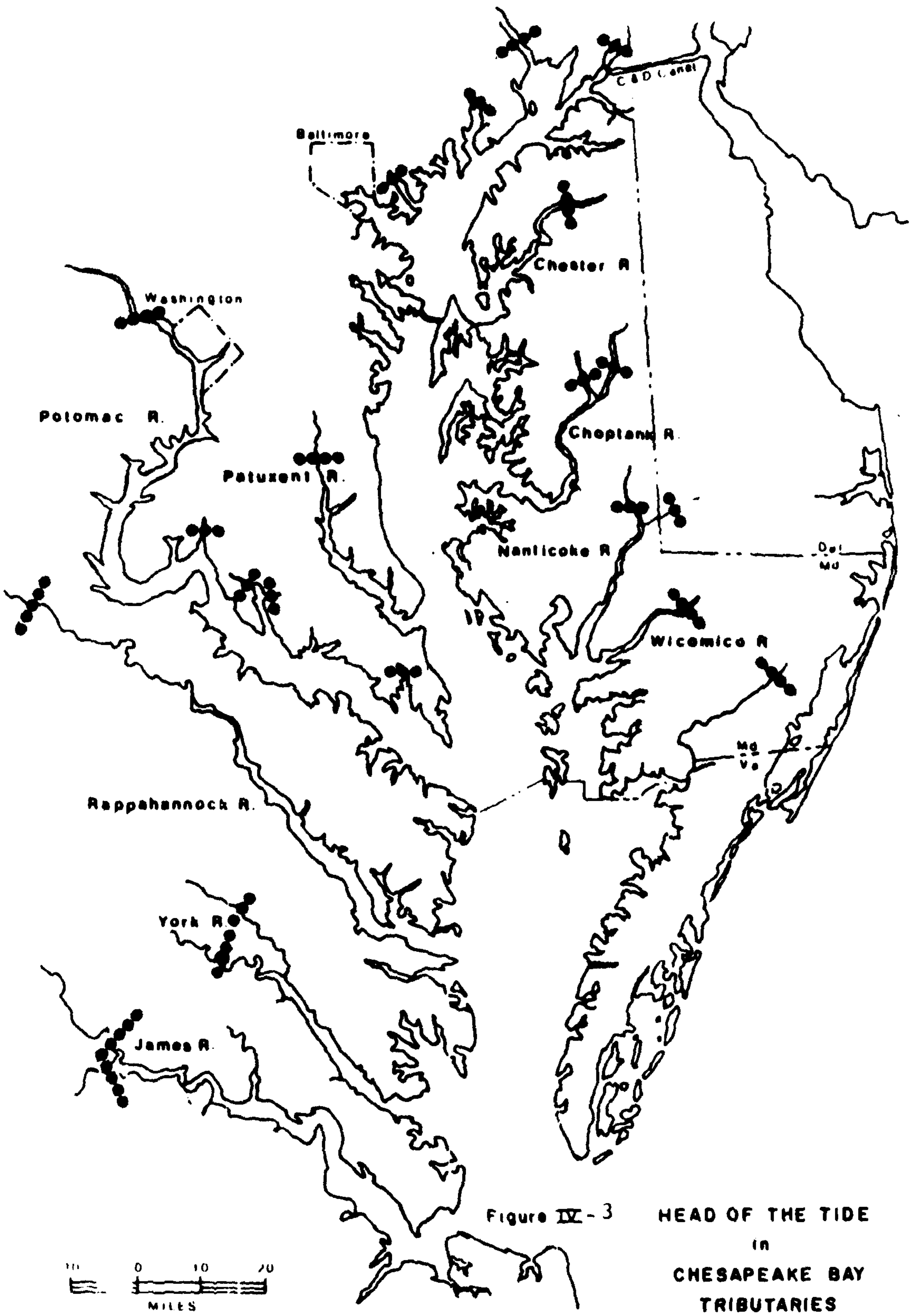

Figure IV - 3 HEAD OF THE TIDE in CHESAPEAKE BAY TRIBUTARIES

Source: Md. Geologic Survey, 1970

C. CHEMICAL BASELINE CONDITIONS

In addition to salinity (already discussed above) water contains minerals and organic compounds. Some of these are beneficial nutrients within a certain range of concentrations and some are detrimental over nearly every range of concentration. The existence of a water quality problem, defined here as the presence of undesirable substances or undesirable concentrations of beneficial nutrients, will have a direct bearing on the impact of low freshwater inflows. Peak water usage frequently accompanies low river flows. This simultaneously increases the volume of waste effluent and reduces the water available for dilution and thereby aggravates existing problems and creastes new ones where water quality conditions were marginal. Calculation of such differences on a Bay-wide basis are beyond the scope of the present study.

Water quality considerations, per se, have been judged to be basically beyond the scope of the Biota Assessment. In comparing present average or low flow conditions to scenarios for 2020, water quality conditions will be assumed to remain constant. Since water quality and, in particular, nutrient concentrations do influence organism distribution, some account of these conditions must be made, and some rationale must establish baseline conditions.

Water quality as it influences organism distribution will only be considered in areas known to be totally inhospitable to certain organism types due to heavy pollution. This occurs in certain heavily urbanized areas and below certain sewage treatment plants. To eliminate such anomolous influences, such areas will be considered not to exist for mapping purposes or as habitat for these organisms.

Nutrient baseline data varies by river system. Nutrient conditions defining a baseline will be those average or low flow year studies (as the case may be) judged most representative for the Bay (or tributaries) segment in question over the 1960 - 1980 period. Thus the chemical baseline is variable by river system or Bay segment depending on when applicable research has been conducted. In the remainder of this section, major pollution sources and general water quality conditions are presented to document the interaction between flow regimes and chemical conditions.

Figure VI- 4 illustrates the water quality study regions used in the Future Conditions Report. Water quality conditions which have a potential interaction with the low flow Biota Assessment are addressed in each of the six study sections. An assumpation of the low freshwater inflow Biota Assessment is that essentially present levels of water quality will be maintained through the year 2020. This assumption is made so that comparitive analyses of salinity change can be made while holding most other major variables fixed. Considering the projected increase in population and indistrialization by the year 2020, a significant improvement in pollution control technology will be required merely to prevent deterioration of water quality. Some of the current conditions can be seen from Table IV-3 .

Each study area receives effluent from point sources and non-point sources in various degrees depending on the intensity and nature of development in the watershed. Pollutant additions from non-point sources are expected to be reduced during periods of low rainfall and low freshwater inflow. Flows through a waste water treatment plant may be expected to remain the same or possibly increase slightly unless water conservation measures are initiated.

The area of closed shellfish beds (in hectares) changes periodically as a result of changes in water quality in the vicinity of the beds. The 1976 data in Table IV- 3 is from the Corps of Engineers <u>Future Conditions Report</u>. The amount of closed area

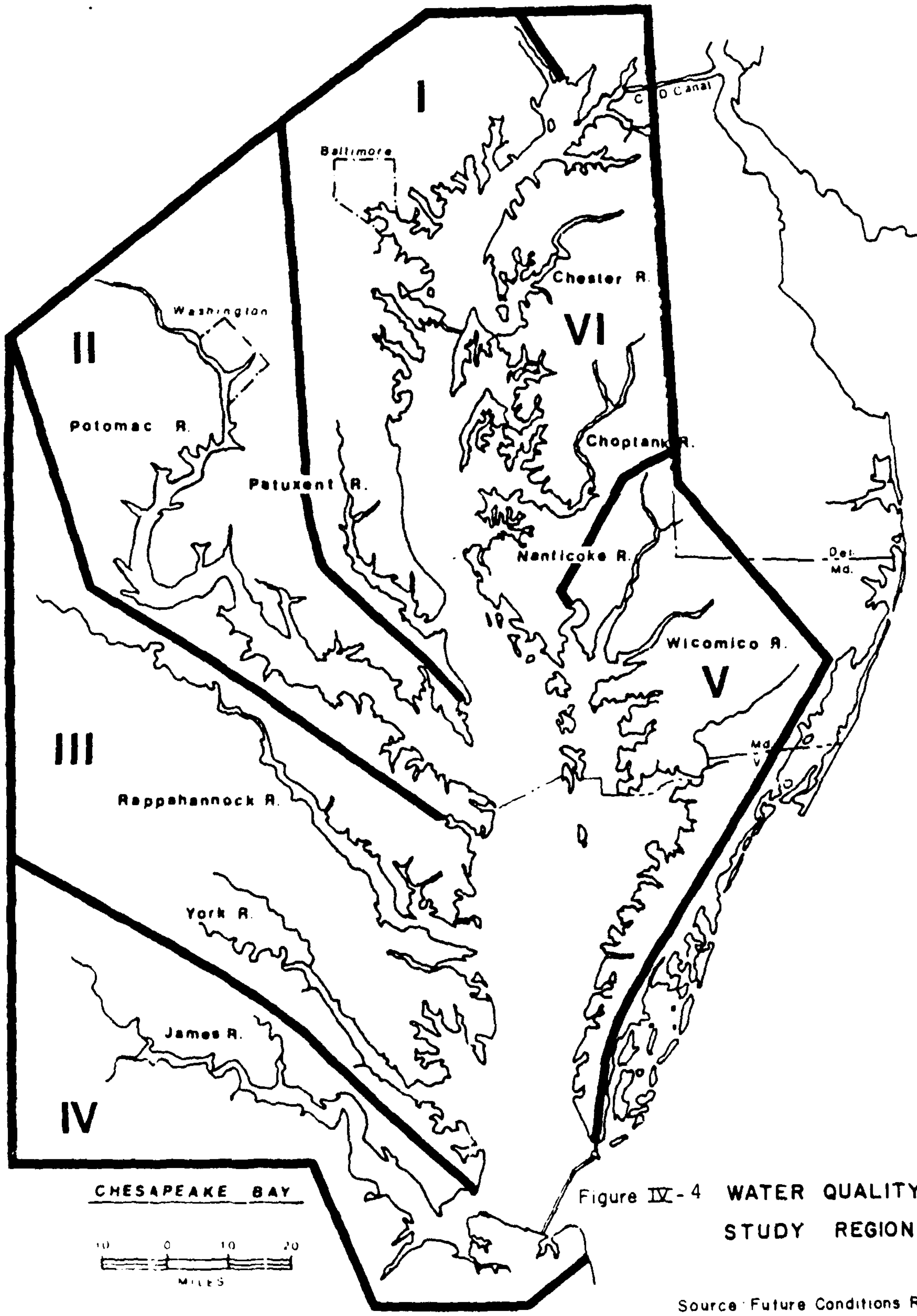

Figure IV-4 WATER QUALITY STUDY REGIONS

Source: Future Conditions Report

TABLE IV-3

Summary of Water Quality Factors Impacting the Low Freshwater Inflow on Biota

Study Region and Major Inflow Source	Drainage Area (Hectares)	Area of Closed Shellfish Beds - 1976 (Hectares)	In Model Projected (Year 2020) Sewage Treatment Effluent (MLD)	In Model 1960 and 1976 Sewage Treatment Effluent (MLD)	Sum of Projected (Year 1990 or 2020) Mean BOD Loadings (Kg/Day)	Other Water Quality Problems
I Susquehanna, C&D Canal, Patuxent (Baltimore metro area)	6,347,845	12,547	1,481	428	7,302	Flow modifications Low D.O. High Temp. High sediment loading Industrial effluent Thermal Heavy metals Chlorine
II Potomac (Washington metro area)	3,799,383	6,167	4,141	1,385 (2,024.8)	13,063	Thermal discharge High sediment loading Chlorine
III Rappahanhock and York	1,376,532	10,927		(43.1)	3,7[illegible]7	Oil spills Industrial effluent High sediment loadings
IV James (Richmond metro area)	2,616,317	24,279	874	299 (712)	17,491	Heavy metals Chlorinated hydrocarbon Pesticides Industrial waste
V Lower Eastern Shore		527		89.3	244	Seafood processing waste Herbicides Pesticides
VI Upper Eastern Shore		13,905		79.9	131	Sediment Herbicides Pesticides

1 mi^2 = 2.5899 sq. km 1 sq km = 100 ha 1 ha = 2.471 acres

is a good general indicator of general sewage pollution conditions.

The figures for sewage treatment plant (STP) effluent in 2020 in millions of liters per day (mpd) are from the Corps of Engineers Low Flow Test description. The values represent the amount of liquid added to the hydraulic model to simulate STP effluents. For the base year 1960, the flows from the model are shown in the next column. For compariative purposes, the sum of designed flows of STP's in 1976 is included in parenthesis. It can be seen that the hydraulic model only simulates a portion of the present known effluent volume in the study area. The Future Conditions Report contains tables of projected mean biological oxygen demand (BOD) loadings. These are summed for each water quality study region. Most of the projections in the Future Conditions Report were for the year 2000; however, a few were for 1990. In the later case, the means were summed with the year 2000 values with no attempt to extrapolate. Actual BOD values will vary with freshwater inflow and temperature as well as effluent volume.

Other water quality problems include thermal additions, heavy metals, oil and grease, sediment (turbidity), pesticide and herbicide runoff from agricultural areas. These problems are not specifically addressed in the Low Flow Biota Assessment.

D. BIOTIC BASELINE CONDITIONS AND FLUCTUATIONS

As with most chemical studies, biological sampling usually occurs in a given tributary or Bay segment, over a limited time period. The diversity of Chesapeake Bay organisms and distributions has precluded comprehensive, wide-ranging studies of more than a few organisms at a time. Since such studies are usually influenced by locations of laboratories, changes in funding, and are often designed for specific problem areas, there is no one year or similar short time period during which enough data exists to set a biological baseline. Therefore, a base period was selected. This base period is the two decade period 1960 - 1980, during which most of the ecologically useful Chesapeake Bay data base has been developed.

With such a long base period, the question of biological variability becomes important. Since almost no examples of longterm (20 year or longer) baywide population studies exist, the only available data is that of commercial catches of fish and shellfish. While the economics of the fishing industry probably have some effect on this data, Ulanowicz et al. (1980 a,b) have shown that such data is controlled mostly by natural factors. It may, in fact, be possible to largely eliminate economic effects through regression analysis with economic indices. In the text below, we discuss long term commercial fluctuations where such data exists. Based on recent studies (Ulanowicz et al. 1980 a, b), such data may be fairly representative of the relative (not absolute) magnitude of biological population fluctuations.

Cycles in production (and standing stock) have interested biologists since the early part of this century. Terrestrial ecological studies have established that the closer a population is to the carrying capacity of the environment the greater is the impact of meteorological changes on the population size (Watt 1968). No one knowns the carrying capacity of Chesapeake Bay, even for any single species. However, the influence of meteorological cycles has been detected on some species (Massmann and Pacheco 1960, Dorel 1968, Joseph 1972, Wiley et al. 1978, Ulanowicz et al. 1980) and suggested in others.

Historical population estimates provide some idea of environmental carrying capabilities. This is useful, even though there is no assurance that the environment has not already been modified to the point where the carrying capacity is less than represented by historical data. To illustrate the difficulty in using historical estimates as a means of establishing baseline conditions, we have examined the harvest data for shellfish, six finfish species and waterfowl from Chesapeake Bay from the years 1950 through 1979. Computer correlation tests against economic and physical variables were run for some of these species. Since all data sources used in this section reported in English units, these units will be used. Summary tables also provide metric units.

Table IV-4 presents the relative importance of nine Chesapeake Bay species. Each species is ranked on the basis of weight of catch. A notable shift has occurred in the rankings between 1960 and mid-70's with spot and bluefish reversing their relative positions in the sport catch. This reflects changes in abundance of these fish populations. The highest catch in the sport fishery is of bluefish and striped bass, both top predators which depend on an abundance of smaller fish and invertebrates.

Fifty two species of finfish are landed commercially from Chesapeake Bay waters. Of these,twelve species are landed in amounts over a million pounds (in 1973). Most numerous were:

1. Menhaden landings - 505.6 million lbs.
2. Alewives landings - 11.3 million lbs.
3. Striped bass landings - 7.8 million lbs.
4. Weakfish landings - 5.6 million lbs.
5. Fluke landings - 3.7 million lbs.
6. Bluefish landings - 3.1 million lbs.
7. Shad landings - 3.0 million lbs.
8. Spot landings - 2.6 million lbs.

All except menhaden and alewives are subject to harvest pressure from the sport fishery. The overlap of sport and commercial species indicates that the list of important species which might be agreed to by both sport and commercial fisheries would be a relatively short one. There would probably be general agreement throughout the bay region that the top ranking six will include Moronids (striped bass and white perch), Sciaenids (weakfish, spot and croaker) and the Pomatomids (bluefish).

Production of these important species is vitally dependent upon

Table IV-4

Ranked Relative Importance of Species Fished for Sport in Chesapeake Bay (by pounds landed)

Year -	1976[1]	1974	1960[2]	1960[1]	Average
Source -	Speir et al.	NMFS	Richards	Shearer et al.	of Rankings
Blue-fish	1	1	-	5	2.3
Striped Bass	2	2	4	2	2.5
Summer Flounder	3.5	3	6	9	5.4
Weak-fish	3.5	4	2	6	3.9
Spot	5	5	1	1	3.0
Atlantic Croaker	6	6.5	3	4	4.9
Eel	7	6.5	-	7	7.0
White Perch	3	-	-	3	3.0
Puffer	-	-	5	8	6.5

1. Covers Maryland waters only

2. Covers Virginia waters only

an abundance of the smaller fish known as forage fish. In this role, the menhaden occupies a unique position. The menhaden feeds on zooplankton and phytoplankton. In turn, menhaden in various life stages are fed on by nearly all sport and commercially important fish. The menhaden can be considered an important species from at least two points of view, the importance to the commercial fishery (in Virginia), and the importance to the food chain of all the higher tophic level predators vital to the sport and commercial fishery.

Table IV-5 illustrates the degree of competition between commercial and recreational fisheries for the same species of finfish. Menhaden landings in Chesapeake Bay have been increasing from a low point in 1955 (Figure IV-5). Menhaden landings are significantly correlated with price per pound and with freshwater inflow over the period 1950 to 1978 at the 0.01 and 0.05 probability levels respectively.

Ulanowicz et al. (1980) also found a positive correlation between landings and low freshwater inflow which coupled with negative air temperature correlation and suggested a fish kill hypothesis for controlling stock size. Menhaden are ocean spawners whose larvae are dependent on meteorological conditions to reach the estuary (Nelson et al. 1977). Meteorological patterns couple with fresh water inflow, so there is the possibility that the actual relationship between landings and inflow is more complex than simple dependence on either salinity or current structure.

Mean menhaden landings for the period 1965 to 1978 were 310.8 million pounds. The catastrophic decline in landings in the year 1978 and the failure of the fishery to recover in 1979 (few fish would have been caught in the remaining four cold months) indicate that the use of mean landings of the past 13 years may not be realistic for the near future. A 28 year mean of 230 million pounds landed would appear to be more realistic.

TABLE IV-5

Commercial and Recreational Important Finfish

Common Name	Species Name	Commercial Use	1973 Rank	Recreational Use	1973 Rank
tlantic menhaden	*Brevoortia tyrannis*	X	1		
lewife	*Alosa pseudoharengus*	X	2	0	
Spot	*Leiostomus zanthurus*	X	8	X	6½
triped bass	*Morone saxatilis*	X	3	X	2
hite perch	*Morone americana*	0		X	3
merican Shad	*Alosa sapidissima*	X	7	X	
eakfish	*Cynosion regalis*	X	4	X	4½
inter flounder	*Pseudopleuronectes americanus*	X	5	X	4½
Catfish	*Ictalurus* spp.	X		X	
Scaup	*Stenotomus chrysops*	X		0	
lack sea bass	*Centropristes striatus*	X		0	
merican eel	*Anguilla rostrata*	X		X	9
ellow perch	*Perca flavescens*	X		X	
arge mouth bass nd Bluegills	*Centrarcids*			X	6½
Bluefish	*Pomatomus saltatrix*	X	6	X	1
utterfish	*Peprillis triacanthus*	X			
tlantic croaker	*Micropogonias undulatus*				8

Rankings are by weight landed (or caught) within tidal region (study area).
Key= X = important use   O = occassional use or low volume use   Source-National Marine Fisheries Ser.

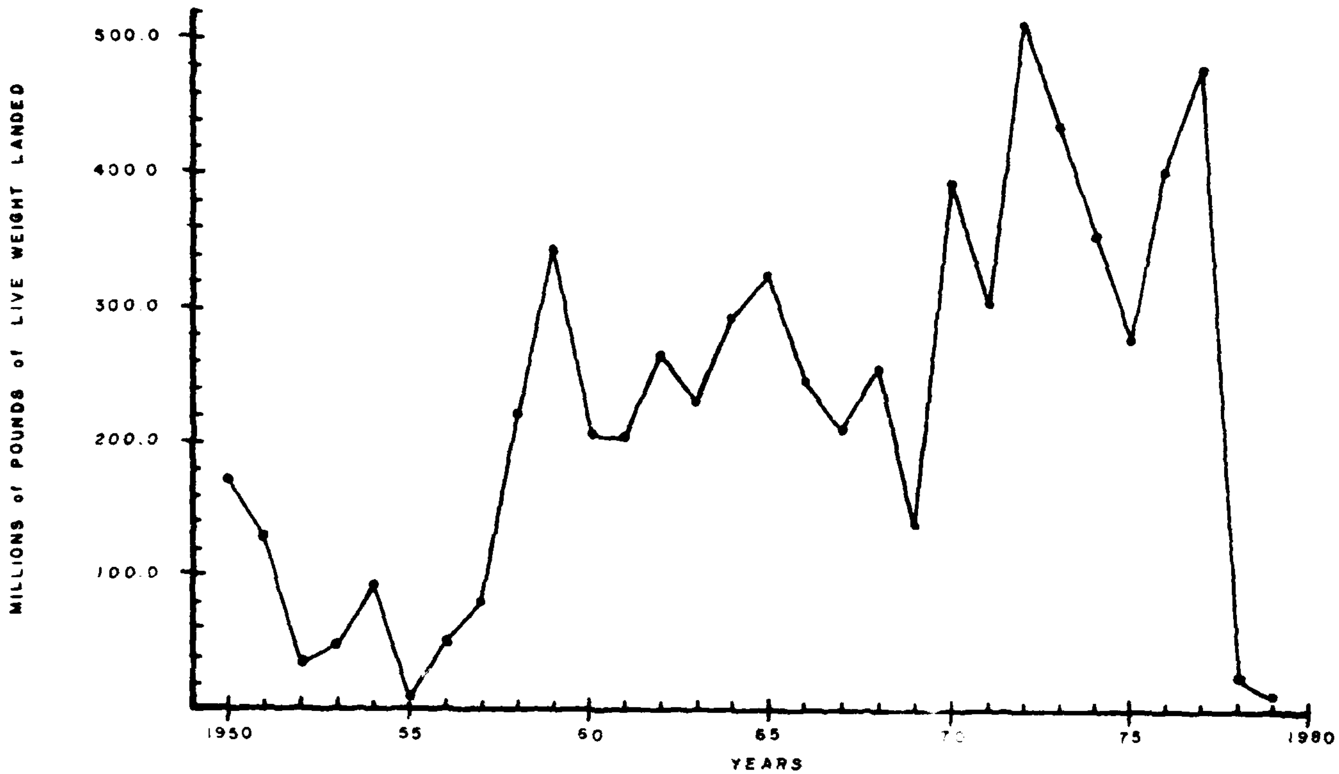

Figure IV-5 MENHADEN LANDINGS IN CHESAPEAKE BAY
1950 - 1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S 1937-1979 (1979, Jan.-Sept. only)

Atlantic croaker have a similar early life history to the menhaden, spawning at sea and depending on meteorological conditions to reach the estuary (Bleil 1978). Historical abundances have fluctuated dramatically but have been at low population levels in Chesapeake Bay since 1960 (Figure IV-6). There is currently no evidence to suggest that populations will again reach their abundances of the early 1930's and mid-1940's. A mean value of 3 million pounds was landed during the period 1952 to 1978 which is taken as a reasonable baseline for the atlantic croaker. Croaker landings are not significantly correlated with freshwater inflow.

Spot landings (Figure IV-7) show the abrupt fluctuations which are characteristic of a short-lived species. The pre-1965 mean of landings was higher but not statistically significant from the mean of landings past 1965. Baseline landings are 2,903 thousand pounds. The spot is also a marine spawner whose young enter the estuary in the drift of bottom waters. As with the croaker, a potential for impact from low freshwater inflows would exist in the distruption (if it occurs) in the up-Bay draft of bottom water. Computer tests show no correlation of spot landings with freshwater inflow over the 1950 to 1978 period.

Butterfish is a pelagic spawner with the young probably dependent on estuaries (Fritzsche 1978). Juvenile butterfish associate with the medusa of jellyfish which provide protection and food (Mansueti 1963). Butterfish prefer the salinities of the lower Bay, being infrequently caught north of the Patuxent River (Hildebrand and Schroeder 1928, Fritzsche 1978). The landings of butterfish are significantly correlated with low freshwater inflow (error probability $p < 0.02$) and price ($p < 0.01$). The partial correlation coefficient of landings with inflow (with the effects of price on landings removed) is significant ($p < 0.10$). This can be seen in Figure IV-8 where the low freshwater periods of 1954 and 1964-65 show peaks of landings. The fact that the peaks coincide with the dry periods indicates that the higher salinities of low flow years permit more butterfish to penetrate further into the estuary thus be more available to capture. The mean of butterfish landings past 1965 (Of 400 thousand pounds) is lower than the mean of

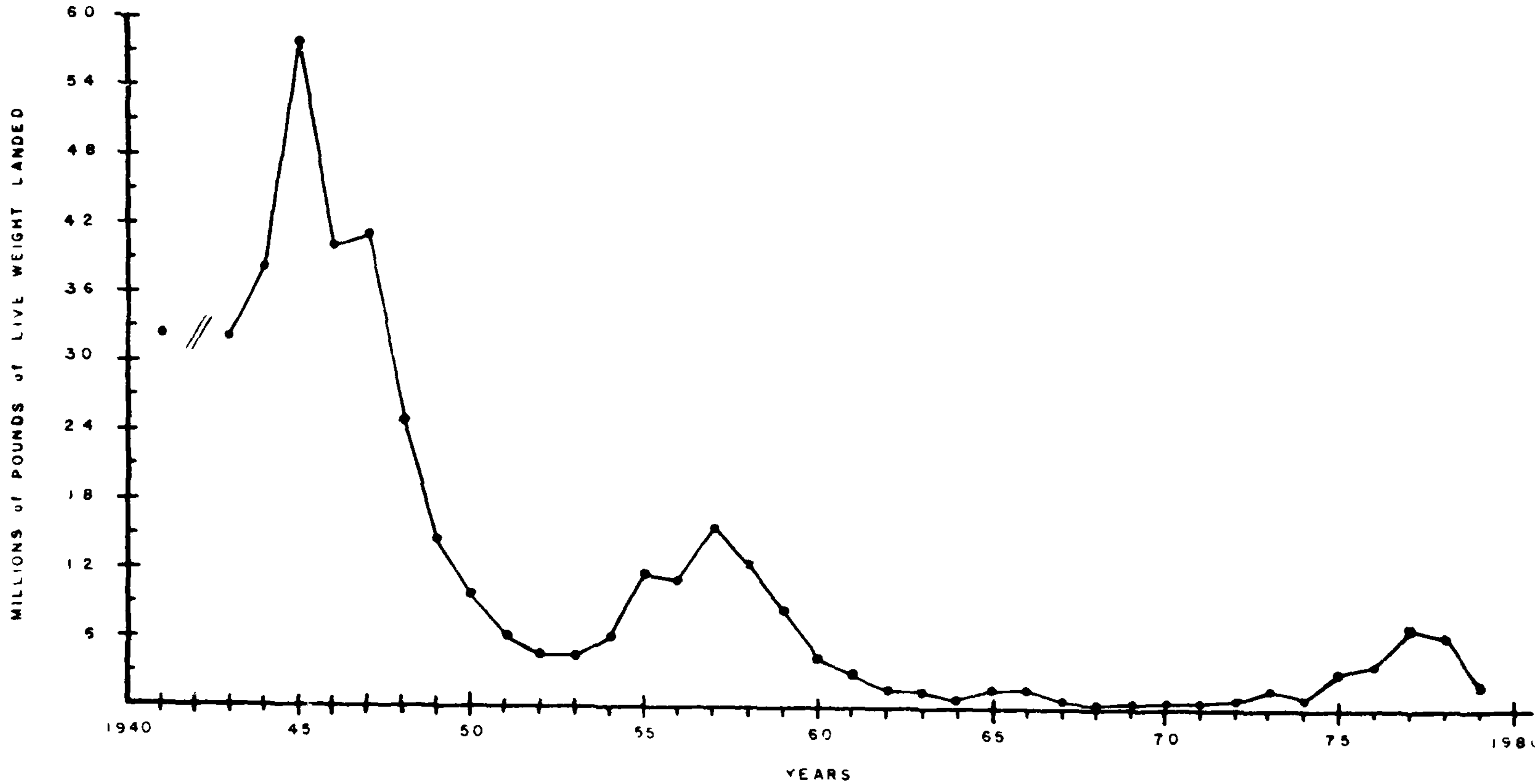

Figure IV-6 **ATLANTIC CROAKER LANDINGS IN CHESAPEAKE BAY**

1941–1979

Source: National Marine Fisheries Service Fishery Statistics of the U.S. 1937-1979   (1979, Jan -Sept only)

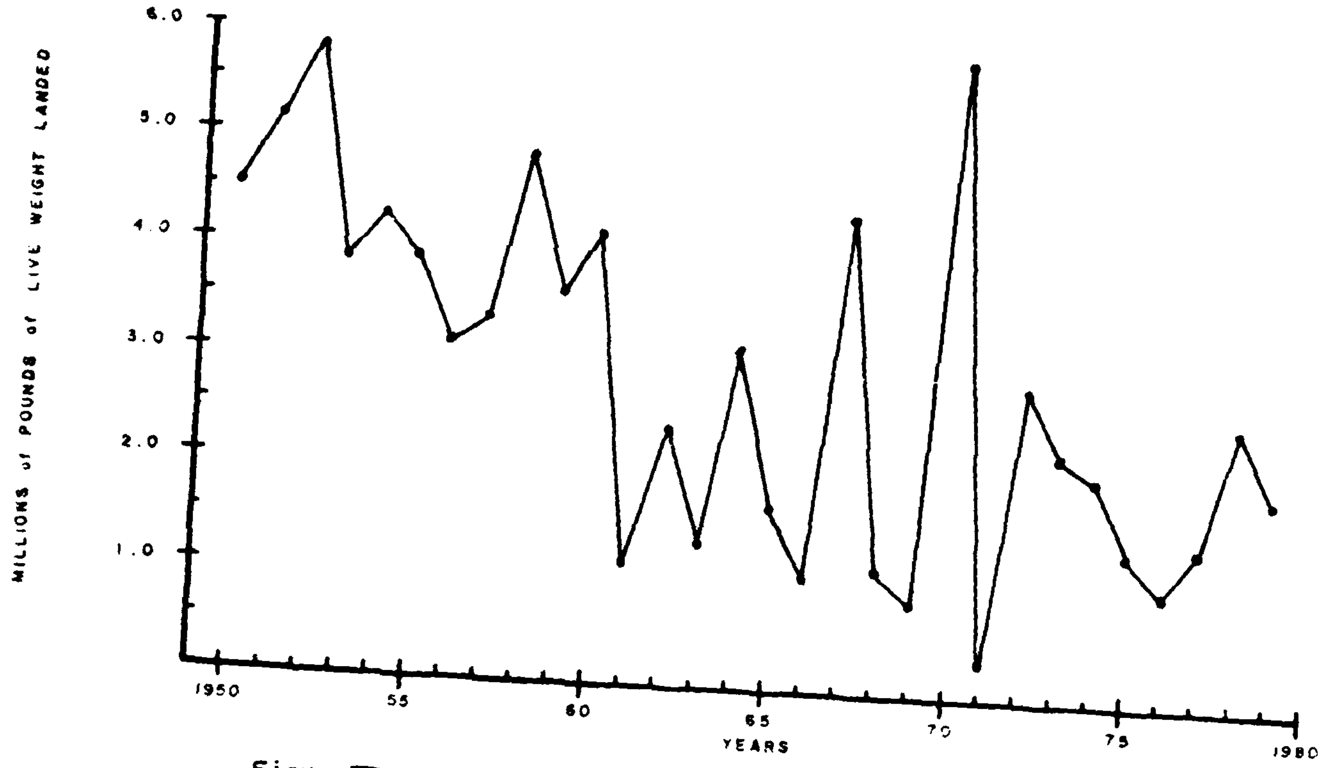

Figure IV-7 **SPOT LANDINGS IN CHESAPEAKE BAY**

1950 – 1979

Source: National Marine Fisheries Service   Fishery Statistics of the U.S. 337- 373   373 Jan Sept

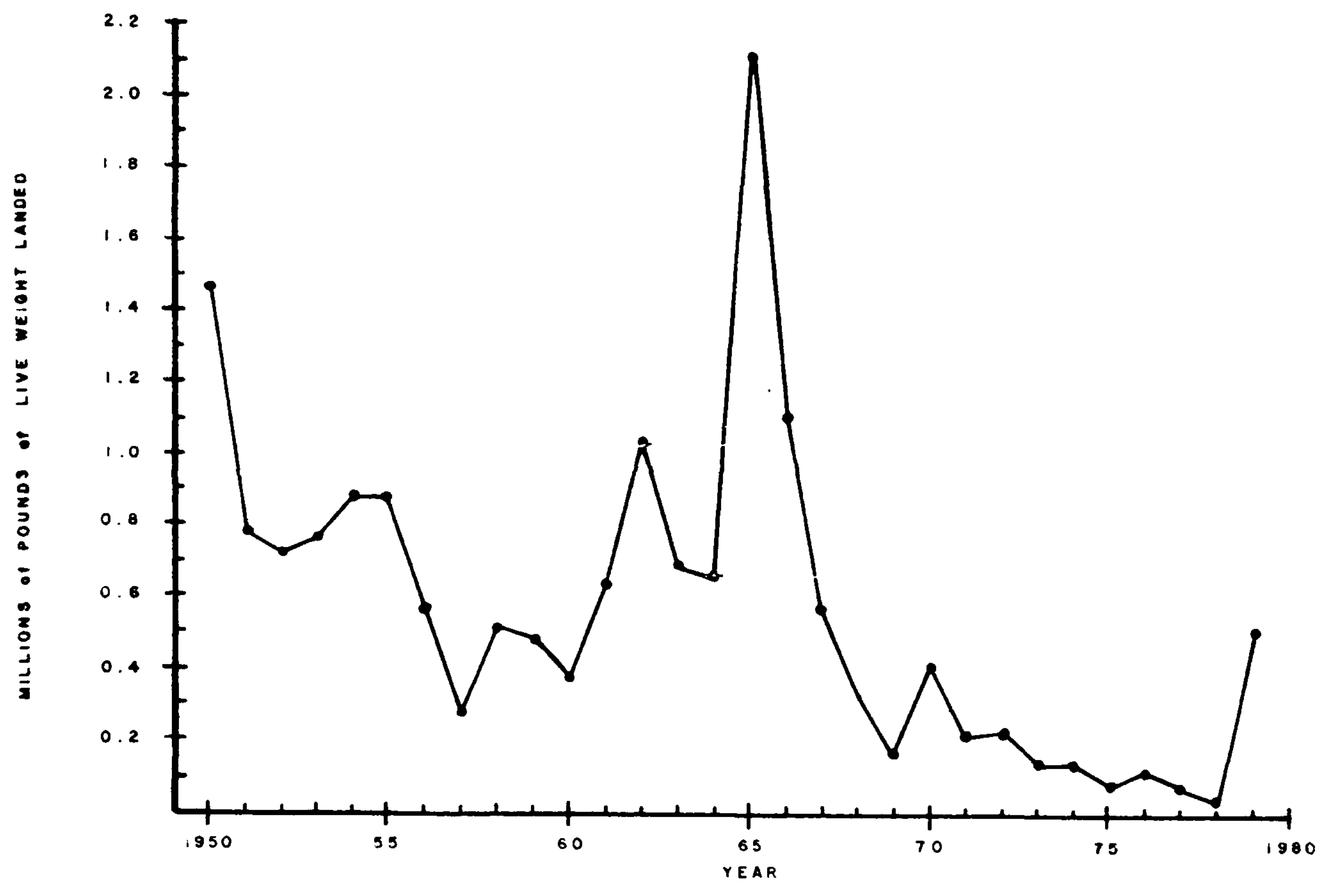

Figure IV-8 **BUTTERFISH LANDINGS IN CHESAPEAKE BAY**

1950 – 1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S. 1937-1979 (1979, Jan.-Sept on pre-1965 landings. The more recent period thus appears to be more indicative of baseline conditions from which populations would be expected to increase during periods of drought and consumptive water loss.

Bluefish landings have increased dramatically since 1970 (Figure IV-9). The bluefish is a marine spawning fish which feeds in the estuary during summer as adults and sub-adults. Ulanowicz et al. (1980) feels that episodes of drought and higher water temperature favor the penetration of bluefish in Chesapeake Bay. However, from examination of Figure IV-9, it can be seen that landings were declining during the 1964-65 drought and they have been quite high during recent periods of higher than average flows so the extent that the bluefish would respond to low flows and consumptive water loss is still an open question. Commercial landings of bluefish reflect to a certain extent the reduction in population size of striped bass, an ecological competitor in the Bay. The bluefish will not be used to establish a baseline landings figure for impact assessment.

Striped bass are anadromous spawners. The abundance of a given year class is governed by a complex set of conditions in the tributaries to Chesapeake Bay, including the C & D canal (Wiley et al. 1978, Setzler et al. 1979, Beaven and Mihursky 1980). Since 1970 conditions have not been favorable for the production of a dominant year class capable of sustaining the fishery at historical levels of landings.

Striped bass landings per se (Figure IV-10) do not show a correlation with freshwater inflow over the period 1950 to 1978. However, freshwater inflow has been correlated with high survival rates of juveniles (Polgar et al. 1976). High water inflow delivers large amounts of detritus to nursery areas, supporting high production of copepod Eurytemora (Heinle and Flemer 1975), which is an important food source for striped bass larvae and young juveniles (Setzler et al. 1979, Beaven and Mihursky 1980).

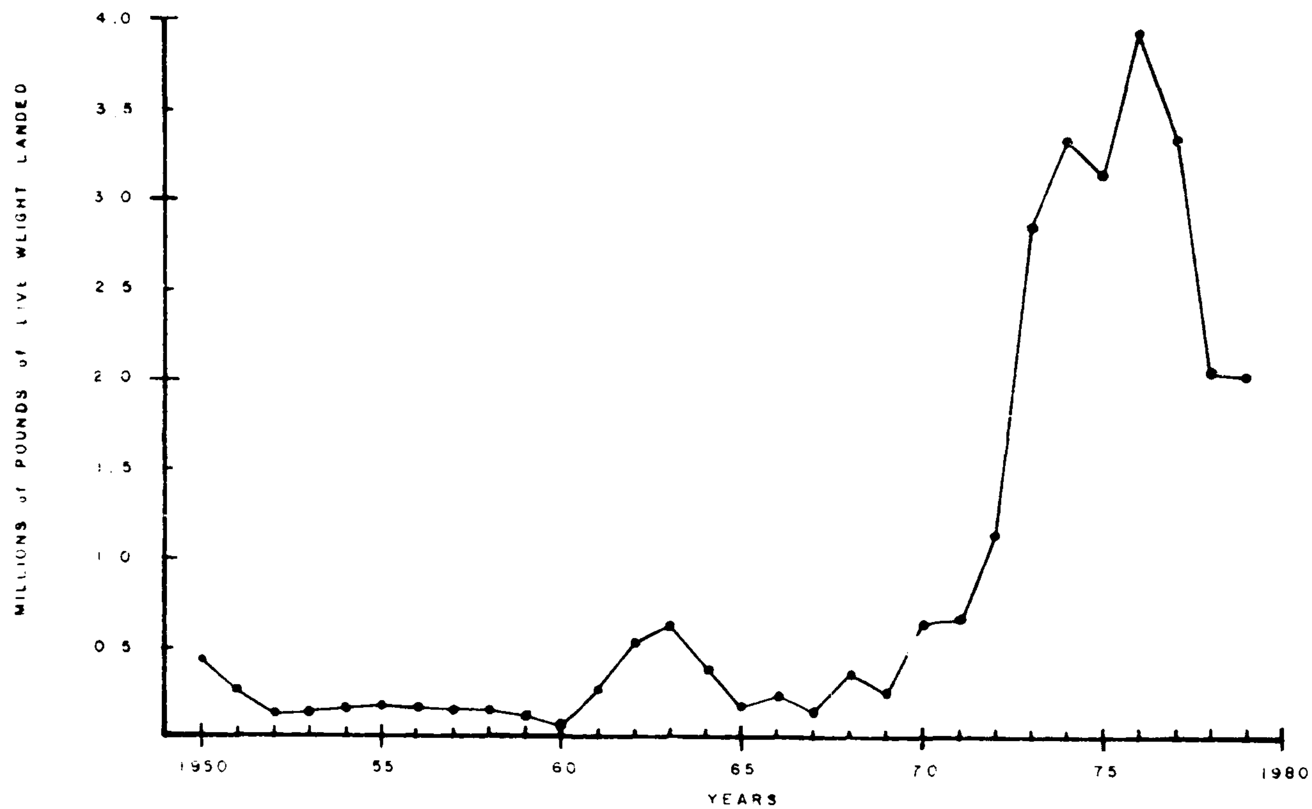

Figure IV-9 **BLUEFISH LANDINGS IN CHESAPEAKE BAY**
1950 – 1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S. 1937-1979 (1979, Jan.-Sept. only)

AD-A125 261 CHESAPEAKE BAY LOW FRESHWATER INFLOW STUDY BIOTA ASSESSMENT PHASE I VOLUME I(U) WESTERN ECO-SYSTEMS TECHNOLOGY INC BOTHELL WA G B SHEA ET AL. AUG 80 3/3

UNCLASSIFIED DACW31-79-C-0056 F/G 6/6 NL

END

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1.0 2.8 2.5
4.5 5.0 5.6 6.3 7.1 8.0 9.0
3.2 2.2
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1.25 1.4 1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

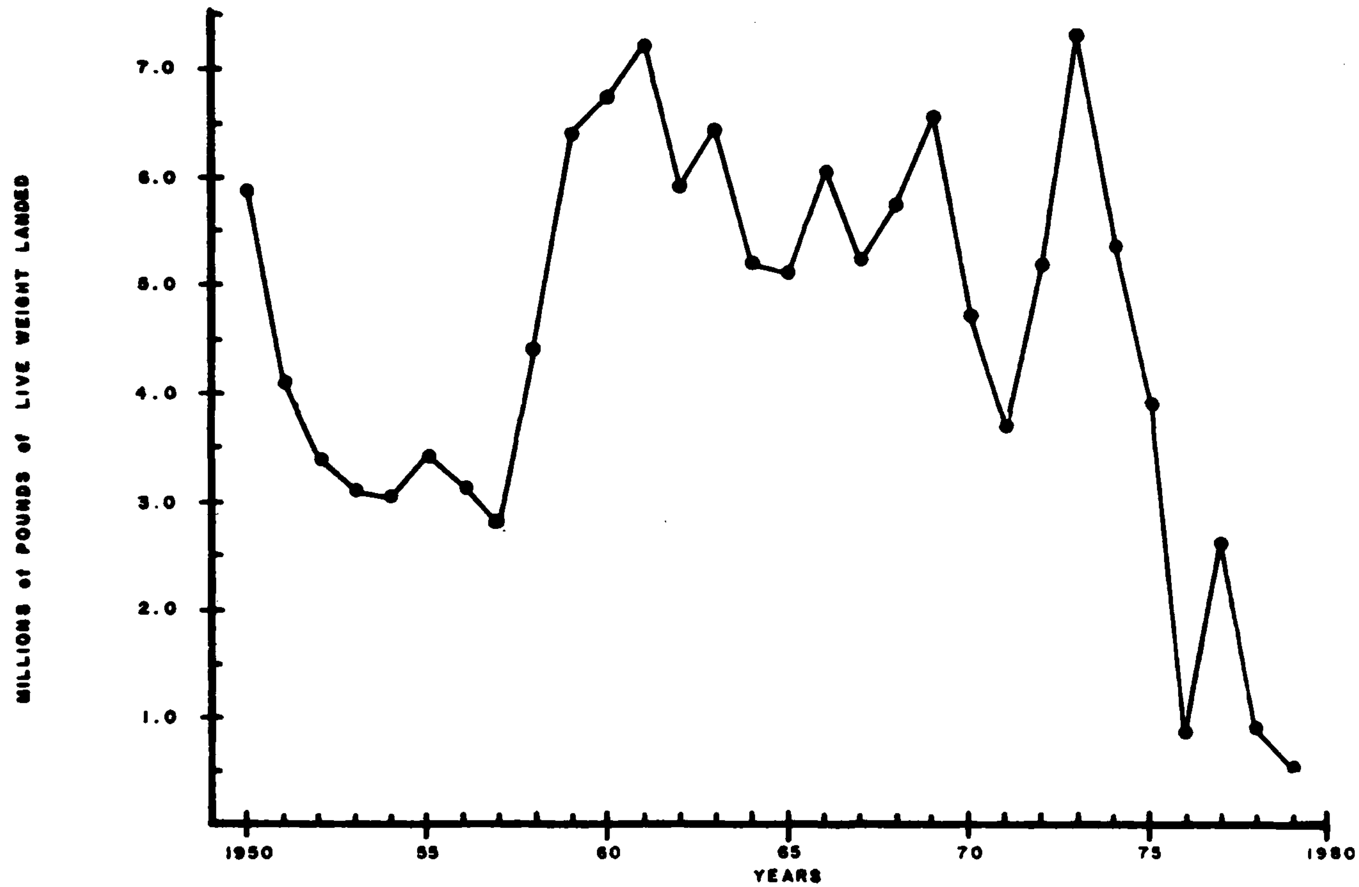

Figure IV-10 STRIPED BASS LANDINGS IN CHESAPEAKE BAY 1950 – 1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S. 1937–1979 (1979, Jan.-Sept only)

Over the period 1950-1978, the mean landings of striped bass were 4,563 thousand pounds with a standard deviation of $\pm$ 1,759 thousand pounds. Because there is no indication at present that a dominant year class can be expected in the near future, the landings equivalent to one standard deviation below the mean have been tentatively selected as the baseline from which to assess the effects of low freshwater inflow (2,804 thousand pounds).

A general pattern has been observed (Dovel 1968) that during years when ocean spawners do well, anadromous spawners do poorly. Much has been published about the decline in striped bass population.

Another species which has declined to a sufficient extent to cause concern is the American shad (Carter 1980). Figure IV-11 presents and landings of shad in Chesapeake Bay in 1950-1979. The steep decline since 1970 has been even sharper in the Maryland portion of the Bay. Both water quality problems within the Bay and high seas overfishing have been suggested as causing the decline (Carter 1980). If water quality in the tributaries is a contributing factor in the population decline of American shad, consumptive water loss and drought would each serve to aggravate the problem by increasing the concentration of the effluent within the tributaries.

The mean of landings 1970 to 1978, the period of decline, is 2,036 thousand pounds. However, the 1980 closing of the shad fishery in Maryland does not lend itself to the use of landings as indicators of the state of the population. Therefore, shad landings will not be included in establishing baseline conditions for quantitative assessment of the effects of low freshwater inflow although the species will be addressed in qualitative terms.

Important shellfish (invertebrates) include molluscs and crustaceans. The total harvest of shellfish from Chesapeake Bay waters is roughly equal to the food finfish harvest at present when the sport catch and commercial catch are taken into account.

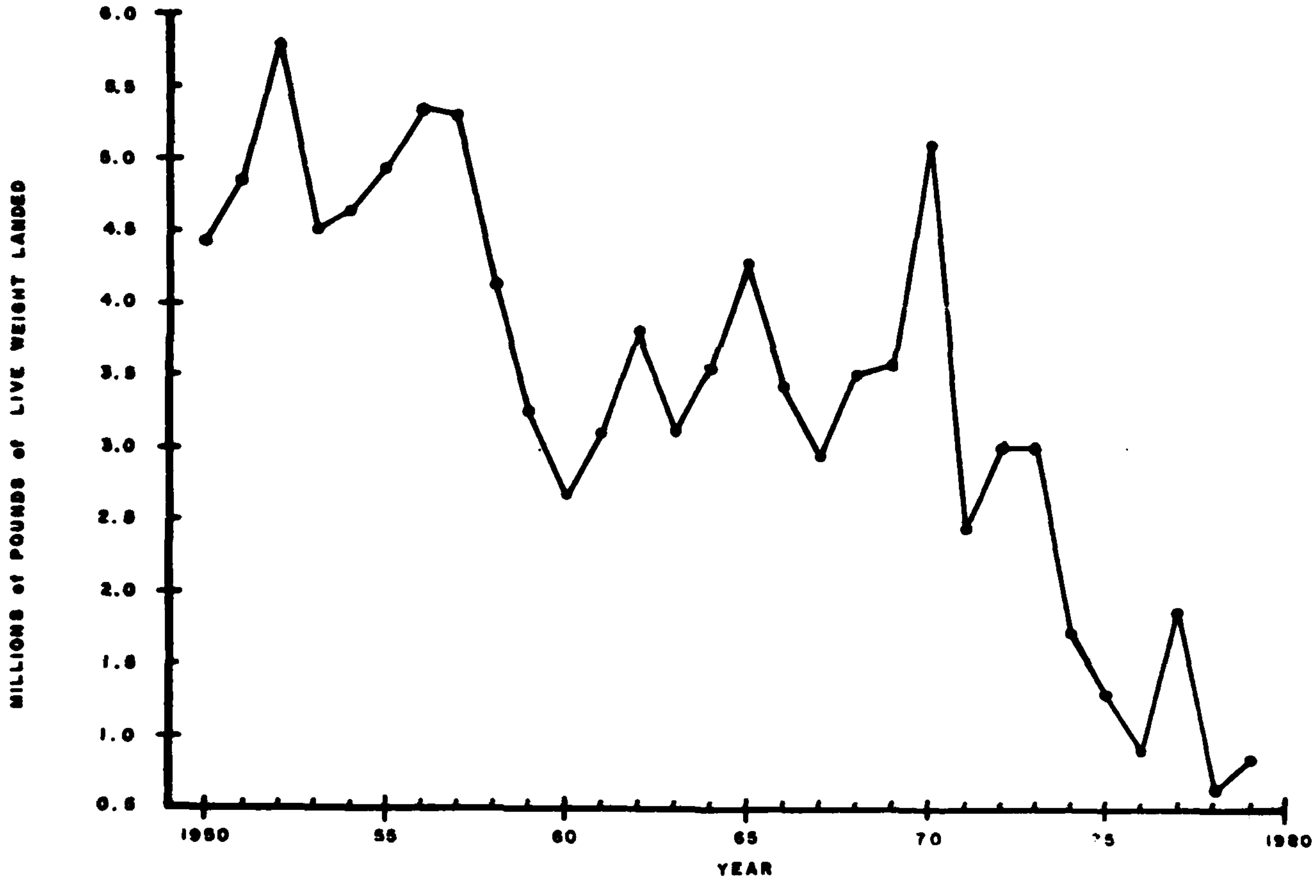

Figure IV-11 SHAD LANDINGS IN CHESAPEAKE BAY
1950-1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S. 1937-1979 (1979, Jan.-Sept. only)

Basically there is one crustacean important to the recreational and the commercial fishery, the blue crab, Callinectes sapidus (Table IV-6). The tasty blue crab is the primary invertebrate species sought after by both the sportsman and the commercial waterman to such an extent that it has become a symbol of the Chesapeake Bay region. This species is important to Chesapeake biota not only for its role in the commerce of the region, but also for its position in the food web of the Bay. It is both predator and scavenger and in turn is fed upon by birds, fish, and man.

Blue crab landings have averaged about 63 million pounds live weight over the 38 year period (Figure IV-12). From 1950-1964 hard blue crab landings averaged 65 million pounds and 1965-1978 landings averaged 52 million pounds. This decrease was less than one standard deviation in the variation of landings and was not significant statistically. Blue crab landings over the period examined showed no significant correlation either to price per pound or to fresh water inflow in spite of an apparent increase in landings one year after the low inflow periods of 1954 and 1965.

Ulanowicz et al. (1980) reported water temperature as the only factor showing correlation with hard blue crab landings in Maryland. However, Van Engle (personal communication) correlates the occurrence of freshets at time of maximum blue crab spawning in the lower Bay with subsequent reduced catches the following year. Freshets apparently disperse the crab larvae away from the Bay mouth and reduce the number of megalopes entering the Bay.

The second most harvested invertebrate species in Chesapeake Bay is the cupped oyster, Crassostera virginica (also subject to both sport and commercial harvest). Oyster production is intensively managed in Virginia and Maryland using planting of shell, transplanting of spat and large scale movements of immature oysters. Conditions for the reproduction of the oyster have been less than optimum in recent years and the future of this important species is viewed with concern in the Bay area.

TABLE IV-6
Commercial and Recreational Important Shellfish

Species	Common Name	Commercial Rank	Recreational Rank
<u>Callinectes sapidus</u>	blue crab	1	1.
<u>Mercenaria mercenaria</u>	hard clam		
<u>Mya arenaria</u>	soft clam	2	
<u>Crassostrea virginica</u>	oyster	2	2.
<u>Rangia cuneata</u>	brackish water clam		

Rankings based on amount landed.

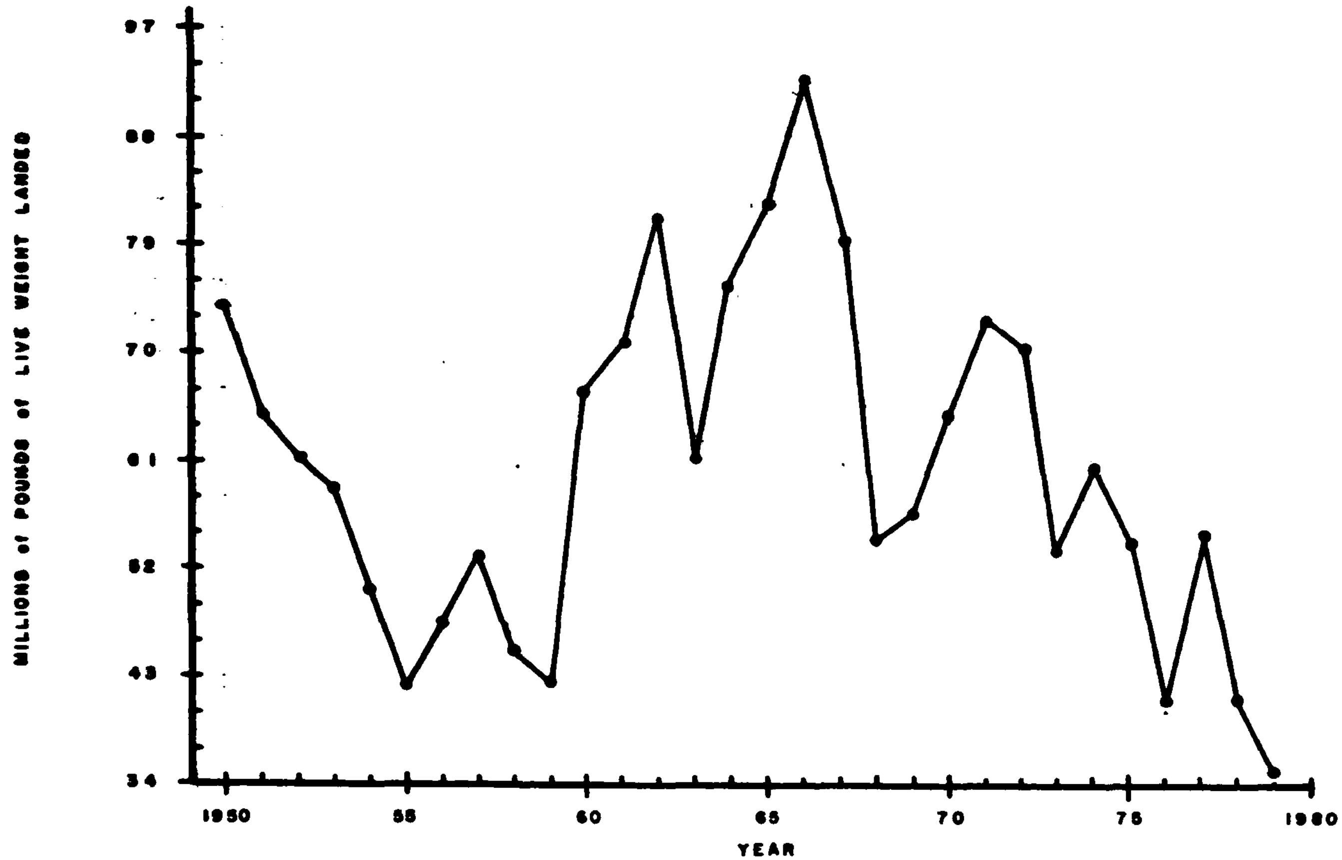

Figure IV-12 HARD SHELL BLUE CRAB LANDINGS IN CHESAPEAKE BAY 1950-1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S. 1937-1979 (1979, Jan.-Sept. only)

Figure IV-13 illustrates the landings of oysters from Maryland and Virginia. During the mid-1950's, a long period of decline of landings set in, which lasted through 1963. Oyster landings have never recovered to their previous levels and recent evidence indicates a second period of decline has set in. Much of the decline in oyster population is believed due to reproductive failure. The mean of the annual oyster landings, 1940 to 1959, was 32 million pounds while the mean of the annual landings, 1960 to 1978, was 21.5 million pounds.

The use of either period to establish a baseline raises some question. The post-1960 period mean landings are more indicative of current carrying capacity but ignores the fact that the Bay could produce considerably higher yields. However, the consumptive water losses anticipated by the year 2020 will be operating on populations depressed as they now are. Therefore, the recent past (post-1960) is the obvious choice for the baseline even though it represents less than ideal conditions.

Kranz (personal communication) notes that periods of increased spat fall and recruitment success occur during episodes of higher salinity. It should also be noted that the spat set of a given year is harvested about 3 years later. Therefore, any direct effects due to the 1964-65 drought should have become apparent after a lag of 3 years. Since a decline in harvest does occur for the year-class 3 years after the 1954 dry year and after the 1964-65 drought, this would indicate that the dry periods may have an adverse effect on survival. That this is not the only adverse effect is evident from the current decline even though the period since 1972 has had higher than average inflow. Ulanowicz _et al_.(1980) suggests that an interaction between low water temperature and higher salinities is favorable to oyster reproduction, with low temperatures being the more important single variable.

Hard clams and soft clams are also important in the economy of the Bay and its trophic structure. The clams live in soft bottom sediments which predominate in the Chesapeake. Clams are also important as predators on the plankton and as converters of

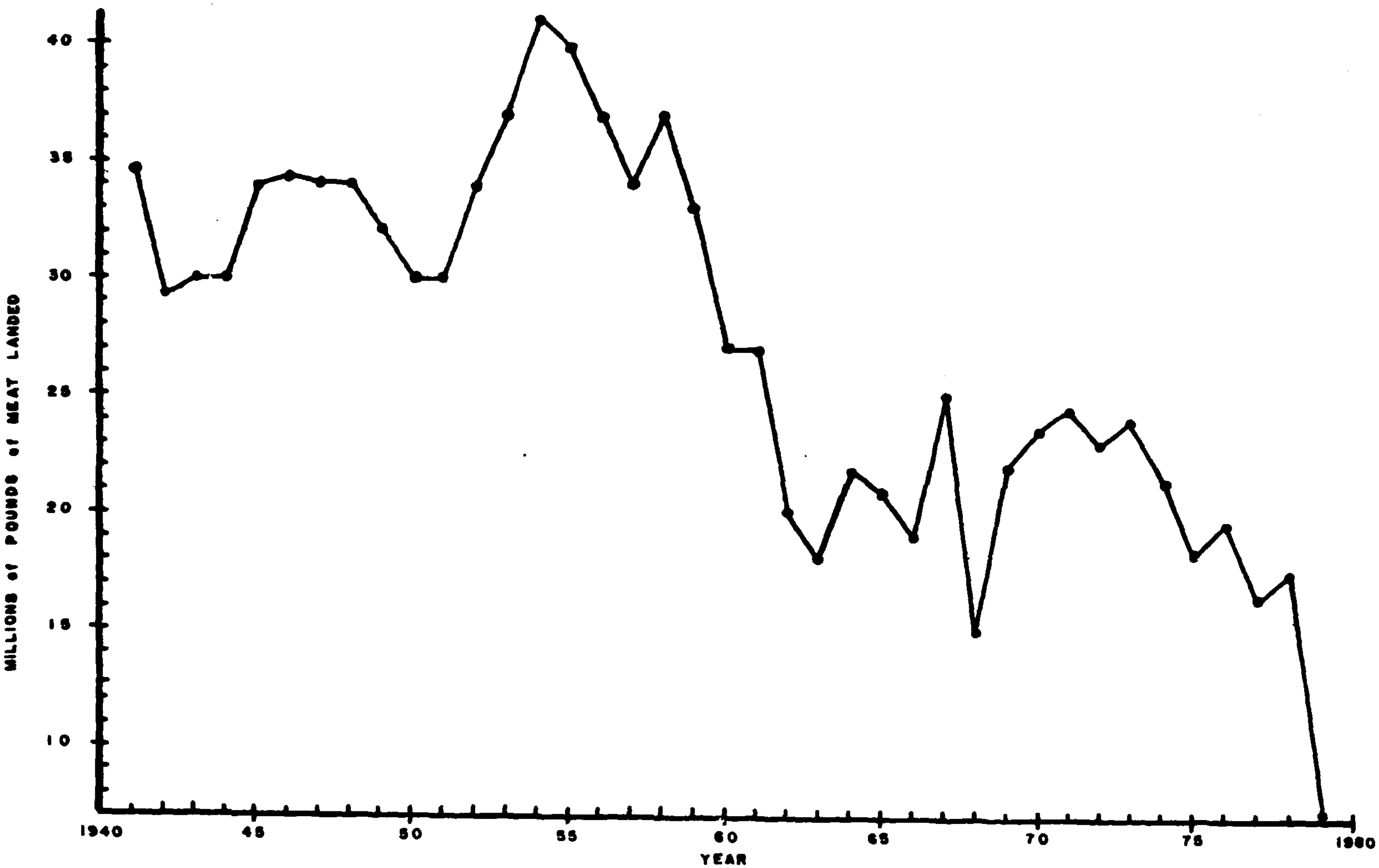

Figure IV-13 COMMERCIAL OYSTER LANDINGS IN CHESAPEAKE BAY, 1941-1979

Source: National Marine Fisheries Service. *Fishery Statistics of the U.S. 1937-1979* (1979, Jan.-Sept. only) bacteria and detritus into food available to fish, birds, and invertebrates as well. The brackish water clam has become an important species recently as a source of waterfowl food (Perry and Uhler 1976). This change in food source for some of the ducks appears to be related to the reduction in area of submerged aquatic vegetation which had formerly been the most important food source (Rawls unpublished).

Hard clam landings went from low levels through a series of peaks in the early and late 1960's (Figure IV-14). The abrupt drop in harvest following the 1964-1965 drought followed the low inflow period too closely to have been caused by recruitment failure. Hard clams reach harvestable size in approximately 3 years. A more plausible explanation for the abrupt one-year decline would be an invasion of salinity limited predators such as the whelk, *Busycon carica.*

The mean of hard clam landings, 1950-1964, is not significantly different from the mean of landings in 1965-1978. There is no indication then that current hard clam landings are currently depressed in excess of the historical range of fluctuations. An average of about one thousand pounds landed meats can be considered a reasonable baseline figure for hard clams.

Soft clam landings have increased since 1950 due to the use of the escalator dredge to reach the formerly unharvested subtidal populations. Therefore, the recent portion of the landings graph (Figure IV-15) should not be interpeted as an actual increase in population. Soft clams grow quickly and can reach harvest size in two years. Peaks of clam landings coincide with periods of low freshwater inflow. The abrupt drop in *Mya* landings in 1972 was due to high mortalities following Hurricane Agnes and to closure of the fishery to preserve the remaining clams as brood stock. There is no significant difference in mean soft clam landings pre- and post-1965.

Due to changes in harvesting procedures and restrictions on the fishery, there is no way to infer population changes from landings data. The population decline due to Hurricane Agnes

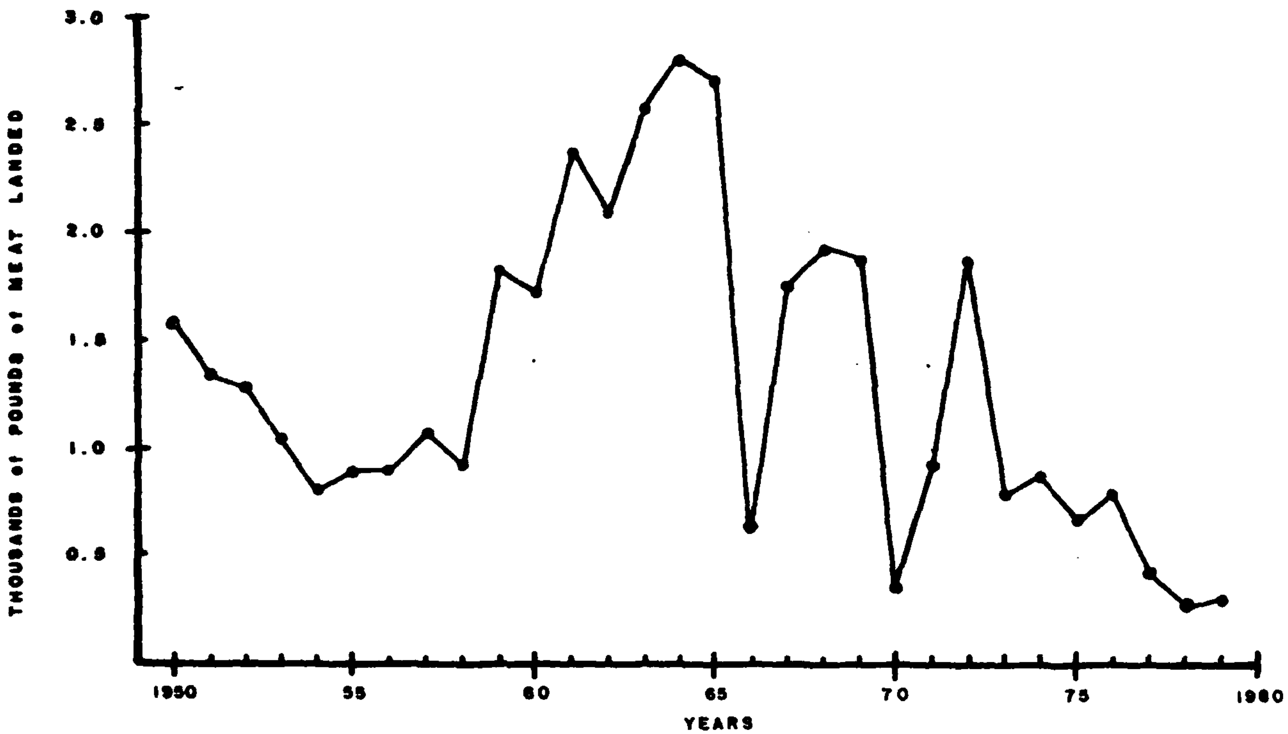

Figure IV-14 HARD CLAMS (*Mercinaria mercinaria*) LANDINGS IN CHESAPEAKE BAY

1950 – 1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S. 1937-1979 (1979, Jan.-Sept. only)

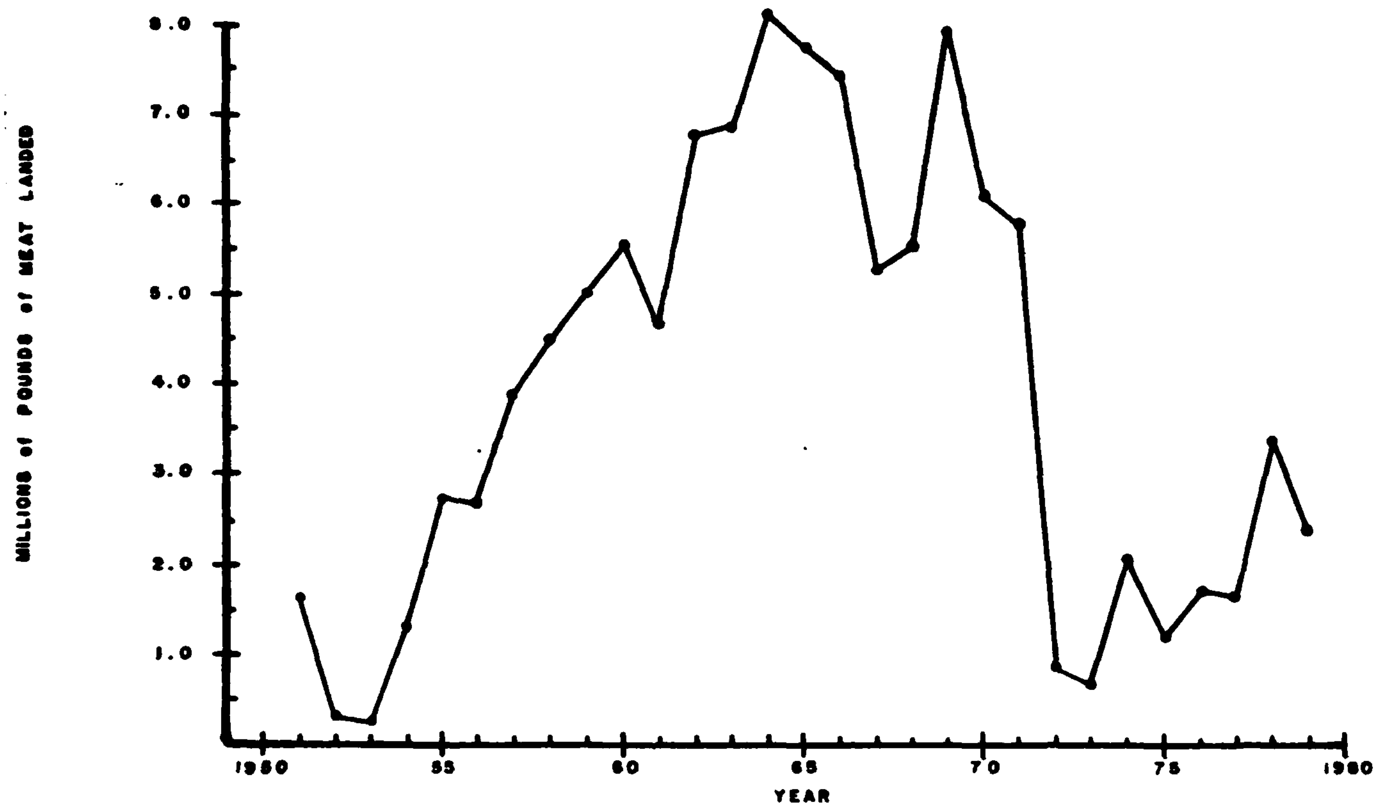

Figure IV-15 SOFT CLAM (*Mya arenaria*) LANDINGS IN CHESAPEAKE BAY

1951 — 1979

Source: National Marine Fisheries Service. Fishery Statistics of the U.S. 1937-1979 (1979, Jan.-Sept. only)

is real and well documented. It is not known yet whether soft clam landings will again increase to their pre-1965 levels.

Table IV-7 shows the waterfowl harvest of Chesapeake Bay and tidewater tributaries for the years 1975 through 1978. The year to year fluctuations are not as great as for some of the fish, reflecting perhaps the success of management. The total harvest is partitioned into percent of yield by the most harvested species in Table IV-8. There is no reason to believe that the average of the four years does not represent a reasonable baseline for assessing the impact of low inflows.

The attempt to establish any sort of baseline in a fluctuating environment is bound to be controversial. For most species which are not subject to commercial harvest, little data is available. This is an important bias in the conduction and interpretation of any study since it seems to imply that the unmentioned species are unimportant, which is not true. It should not be inferred that a baseline figure for harvest represents a desired level of harvest or that a given level of harvest would ever be realized in any given year. Other factors are operating which are not addressed by the low flow Biota Assessment. During the last two or three years, most fish and shellfish species have experienced marked declines. Examination of the landings superimposed would show that fluctuations in the major species are occurring independently of each other. It is only in the past few years that the landings figures all seem to be moving in the same direction - down. This may indicate that a fundamental change has occurred in the carrying capacity of Chesapeake Bay. Such a change will not be completely demonstrable for many years and is completely outside of the scope of this assessment.

Table IV-9 summarizes the baseline harvest or yield values discussed in this section. Discussion of other environmental factors and their relation to inidividual species is contained in Chapter V. Such data will be used to define margins of environmental variability around central values, for both average flow conditions and low flow scenarios.

TABLE IV-7

Waterfowl Harvest* in the Chesapeake Bay

	1975	1976	1977	1978	Four Year Average
Virginia					
Ducks	142,371	139,688	130,077	133,140	136,319
Geese	24,615	22,011	35,056	18,670	25,088
Maryland					
Ducks	164,050	86,493	74,995	163,772	122,327
Geese	189,706	162,034	241,187	118,726	177,913
Total					
Ducks	306,421	226,181	205,072	296,912	258,446
Geese	214,321	184,045	276,243	137,396	203,001

TABLE IV-8

Percent of Total Waterfowl Harvest of Most Hunted Species

	1975	1976	1977	1978	Average Rank of Importance
Ducks:					
Mallard *Anas platyrhynchos*	27.3	29.8	19.39	35.0	1
Black duck *Anas rubripes*	16.9	22.0	10.07	20.0	2
American Wigeon *Mareca penelope*	7.1	7.2	4.63	5.0	5
Green Winged Teal *Anas carolinensis*	6.7	5.6	3.86	8.1	4
Ringnecked *Aythya collaris*	4.4	3.8	2.83	2.8	6
Wood duck *Aix sponsa*	4.1	6.4	13.94	10.6	3
Geese:					
Canada *Branta canadensis*	86.3	93.7	97.3	98.4	1
Brant *Branta bernicla*	7.5	0.1	0.4	0.0	3
Snow *Chen hyperborea*	6.2	6.2	2.3	1.6	2

Source: Carney, S.M. et al. 1978
* Represents retrieved kill

TABLE IV-9

Baseline Harvest Values for Selected Commercial Chesapeake Bay Species

Species	Baseline Average Yield		Relation to Bay Area
Fish	English Units	Metric Units*	Kg/ha
Atlantic Manhaden	230,000,000 lbs	104,326,000 kg	90.72
Atlantic Croeker	3,000,000 lbs	361,000 kg	1.18
Spot	2,903,000 lbs	1,317,000 kg	1.14
Butterfish	400,000 lbs	181,000 kg	0.16
Striped Bass	2,804,000 lbs	1,272,000 kg	1.11
Shellfish			
Blue Crab	63,000,000 lbs	28,576,000 kg	24.85
Oysters	21,500,000 lbs	9,752,000 kg	8.48
Hard Clams	1,000 lbs	500 kg	0.004
Birds			Birds/ha.
Ducks	258,000 birds	258,000 birds	0.224
Geese	203,000 birds	203,000 birds	0.176

*Note, all values rounded.

E. HABITAT CLASSIFICATIONS

The relationship between physical and biological baseline conditions can be best defined by the habitat concept. The factors which control distribution and abundance of organisms are diverse and complex. In order to simplify these factors organization and understanding, it is necessary to find patterns in this observed complexity. The Chesapeake Bay Low Flow Study has, among its objectives, the need to analyze temporal and spatial distributions of organisms, and the effect of habitat changes on that distribution. Thus, classification of those habitats appears both useful and necessary. Such classification will be used in identifying and mapping organism distributions.

Ecologists have attempted to structure and classify habitats, environmental variables, species associations, and trophic rela tionships for well over a century. European terrestrial botanists first related plant distribution to physical features of the environment and to other organisms, and first identified recurring groups or associations (Whittaker 1962). Such classification techniques were applied at an early date to marine environments, notably by Petersen in Denmark (Thorson 1957, Hedgepeth 1957, Odum, Copeland, and McMahan 1974). Petersen's "communities" were recurring groups with characteristic dominant species, occupying certain habitats, not necessarily linked by biotic inter-relationships (Thorson 1957).

Other workers, however, theorized such relationships between the organisms and their environment terming these "communities" or "biocoenoses" (Allee et al. 1949, Whittaker 1962, 1970). The ecosystem was conceived as a collection of biocoenoses, each typical of a certain physical environment (or biotope) (Hedgepeth 1957, Whittaker 1962). These communities have interal organization and are more or less independent of other such associations (e.g. Clements 1928, Whittaker 1962, Odum 1971).

To yet others, the community is a more statistical concept. As such, it reflects the overlapping distributions of individual species populations, each responding in its own way to the environmental variables present (e.g. Gleason 1926, Whittaker 1970, Boesch 1977, Pielou 1977).

1. Classification Methods

This difference in concept had led to two major approaches in classification of environments (Whittaker 1970, Boesch 1971, 1977):

- that based on biological criteria (dominant species, associations, or functional relationships) termed the biocoenotic approach,

- that based on the predominant physical or chemical characteristics of the environment - termed the biotopic approach.

Each has its merits depending upon the environment under consideration and the eventual use of the classified information.

The Chesapeake Bay study deals with the features and structure of the estuary, an environment characterized by strong physical gradients. In addition to salinity, other abiotic features show extensive change along the estuary: substrate, nutrients, turbidity, circulation, depth, and others (Boesch 1971, 1977, Schubel 1972). Thus an estuary is a complex-gradient in the sense of Whittaker (1970), and the physical and biological changes along this constitute an ecoline. Because physical aspects are so dominant in producing this ecoline, we have selected a biotopic approach as that most reasonable for habitat classification in the Biota Assessment.

Several such systems of estuarine classification exist: those based on a single major environemental feature, such as salinity (Venice System) by major energy source or stress (Odum et al. 1974); or by location, substrate, and major habitat modifiers (Cowardin et al. 1977). Initially, WESTECH proposed using the latter classification scheme, which was developed by the U.S. Fish and Wildlife Service for application to wetland and aquatic habitats. This system also had features of the biocoenotic approach, since habitats were eventually characterized by their dominant species or association. The system was hierarchical, easy to comprehend (Pielou 1977) and relatively site-specific. Benefits of such an approach were seen to include ease of mapping, and universiality with respect to other U.S. estuaries.

The system was, however, basically substrate oriented, and other environmental factors such as salinity were used only as modifiers. In addition, it did not consider mobile organisms such as plankton or nekton, which are vital to the estuary. The limitations necessitated extensive revisions of the Cowardin <u>et al</u>. system in order to meet the needs of the Low Flow Study. For this reason, we eventually chose to develop a different classification, retaining some aspects of the Cowardin approach but incorporating major elements from other systems. Since the objective of the Low Flow Study is to document effects of reduced freshwater inflow into the estuary, salinity should be a major component of any habitat classification used.

The salinity gradient is the most obvious characteristic of the estuarine environment. Organisms are distributed along this gradient in response to their physiological tolerances and interactions with other features of the environment, both biotic and abiotic (Boesch 1971). Efforts to subdivide the estuarine salinity regime in a manner showing correlation with organism distribution data from Redeke (1922, 1933), and Valikangas (1933) (cited in Hedgepeth 1957). Working in the Baltic and North Sea areas, these researchers proposed segmentation of brackish waters into the following: freshwater (less than 5 ‰); oligohaline (0.5 to 3.0 ‰); mesohaline, subdivided into alphamesohaline (3.0 to 8.0 ‰), and betamesohaline (8.0 to 16.5 ‰); polyhaline (16.5 to 30.0 ‰); and sea water or marine (over 30.0 ‰).

Other such systems were developed, differing chiefly in the salinities of the various boundaries (Remane 1940, 1971, Ekman 1953). Dahl (1956) discusses the development of these estuarine classification systems, and differentiates between poikilohaline (changing) and homoiohaline (stable) waters. Although Dahl places only fresh and marine waters in the latter cateogory, more recent workers have tended to use "homoiohaline" to categorize brackish waters which show only moderate changes of salinity over time (e.g. Boesch et al. 1976, Boesch 1977) including estuaries such as the mainstem of Chesapeake Bay.

In 1958 an international symposium was held for the purpose of developing a consensus on classification of estuaries and other brackish environments (Symposium on the Classification of Brackish Waters 1959). The following applicable subdivisions were delineated:

Limnetic (Tidal Fresh Water	0.0-0.5 ‰
Oligohaline	0.5-5.0 ‰
Mesohaline	5.0-18.0 ‰
Polyhaline	18.0-30.0 ‰
Euhaline	over 30.0 ‰

This is the "Venice System" widely used both here and abroad to characterize estuarine environments, including those of Chesapeake Bay (Boesch 1971, 1972, Wass et al. 1972, Larsen 1974, Diaz 1977, and others) (Figure IV-16). This system is sometimes modified to include an upper and lower mesohaline zone, separated at 10 ‰ (Lippson et al. 1979 and others).

The Venice System has proven useful and in a general sense the boundaries of the zones correspond to observed breakpoints in organism distributions (Dahl 1956, Remane 1971, Wass et al. 1972). The major strength of the system for purposes of the Biota Assessment is that it permits quantification and categorization of the major variable in the Low Flow Study. The obvious limitation is that the Venice System permits a view of an organisms habitat in only one dimension, that of salinity. It is, however, a starting point for a more detailed classification.

For the Biota Assessment we have expanded the Venice System to include factors other than salinity, particularly substrate, depth, and seasonality. Further details of the expanded Venice System and its application to habitat mapping are discussed in subsec-

FALL SALINITY ZONES in the CHESAPEAKE BAY

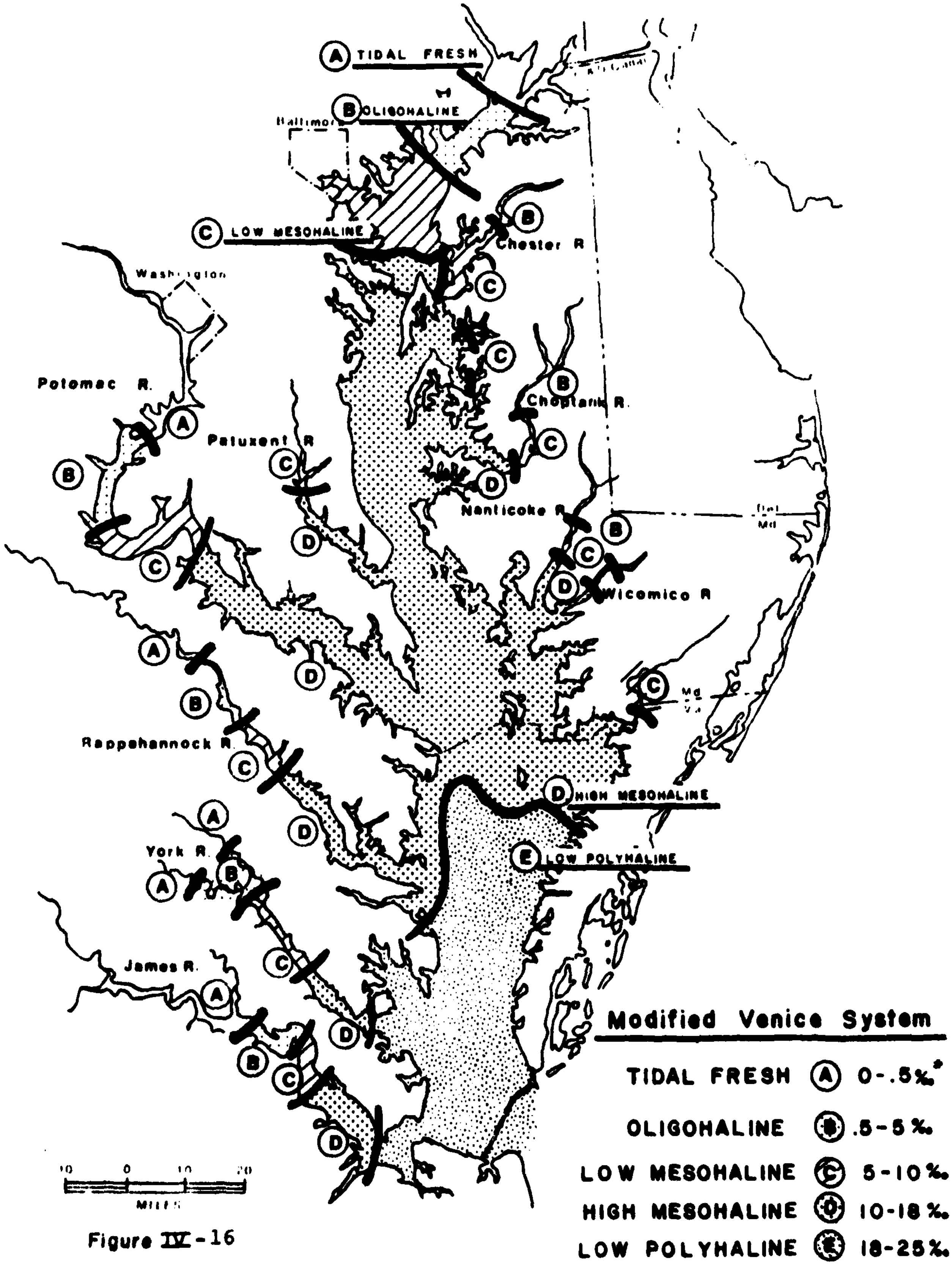

Figure IV-16

* PARTS OF SALT/1000 OF WATER

tion 2 below. We have also avoided imposition of a hierarchical structure (which is not necessary for the purposes of the Low Flow Study) and have added the capability - through use of life stages and seasons - of dealing more effectively with motile organisms.

2. Critical Factors Affecting Biota

Certain critical factors, both biotic and abiotic, affect the distribution of organisms. These variables were considered in our habitat classification scheme, and in the mapping of Study Species distributions. The factors are:

Salinity: Salinity zones are classified by season and depth as mapped during the base year (see Sections IV-A and IV-B). Salinity variations under low flow scenarios will be derived from hydraulic model data in Phase II.

Substrate: Sediments have been mapped on a relatively simple four-category classification system of sand, muddy sand, sandy mud, and mud (Ryan 1953, Shideler 1975). Current programs are underway at both the Maryland Geological Survey and the Virginia Institute of Marine Science for updated sediment analyses of the Bay mainstem, however, these data are not yet available. The updated surveys are expected to give more detailed information on sediments, including particle grain size and geochemical profile information (Reinharz, Bricker and O'Connell 1979, Nilsen, Boesch, and Bertelson 1979). These data should be available during 1980 for Phase II of the Biota Assessment.

Depth: Depth has been used as a habitat modifier only with respect to organisms with well-defined depth preferences or requirements. For example, oysters are generally restricted to depths less than 8 meters (chiefly due to dissolved oxygen limitations), submerged aquatic vegetation is limited by light penetration, to about 2 - 3 meters, and so forth (Haven et al. 1978, Stevenson and Confer 1978).

Seasonality and Temperature: Many organisms occupy a particular habitat only at certain seasons. This may reflect only response to temperature - a major seasonal variable - but also could result from seasonal differences in incident radiation, nutrients, life stage, or availability of food. Seasonal presence or absence of a predator or competition could also affect an organism's distribution (e.g. the reduction of Mnemiopsis leidyi in higher salinity areas in summer and fall by the predaceous ctenophore, Beroe ovata (Burrell and Van Engel 1976)). Seasonality has been used to define and map habitats, wherever sufficient information was available.

Biotic Interactions: Organisms may themselves create a habitat, or modify it to such an extent that they affec the distribution of other species; e.g. the oyster bed (reef) and submerged aquatic vegetation beds, and their associated biota (Marsh 1973, Larsen 1974). In such cases, these species act as substrates, and are treated as such in our habitat classification system. As was discussed under "Seasonality" above, predation and competition can affect an organism's distribution, and must also be considered.

The ways in which these environmental factors affect organism distribution and abundance will be discussed in detail in Chapter V. Each of these factors was used not only to define, but also to map habitat and organism distribution.

The habitat classification as delineated above has been (Phase I) and will be (Phase II) used as a tool during three tasks of the Low Flow Study:

- Enumeration of biological and physical relationships (identification of tolerances, selection of study species, etc.).
- Mapping of distribution of study species.
- Assessment of biological impacts of low flow scenarios.

Because of this third task, we have found it necessary in some cases to differentiate known and potential habitat. Known habitat is defined to be the geographical areas where species have been actually reported. Potential habitats are locations where basic physical and biological conditions are suitable for a species existence, but which have not actually been sampled (Figure IV-17). We recognize that even the best available information does not usually describe all the conditions necessary, for the occurrence of any particular species. Nevertheless, the best data obtainable have been used to map known habitats and extrapolate potential distributions of study species in Chesapeake Bay. These maps are further explained in Chapter V and full scale copies can be found in the Map Atlas (see Chapter I).

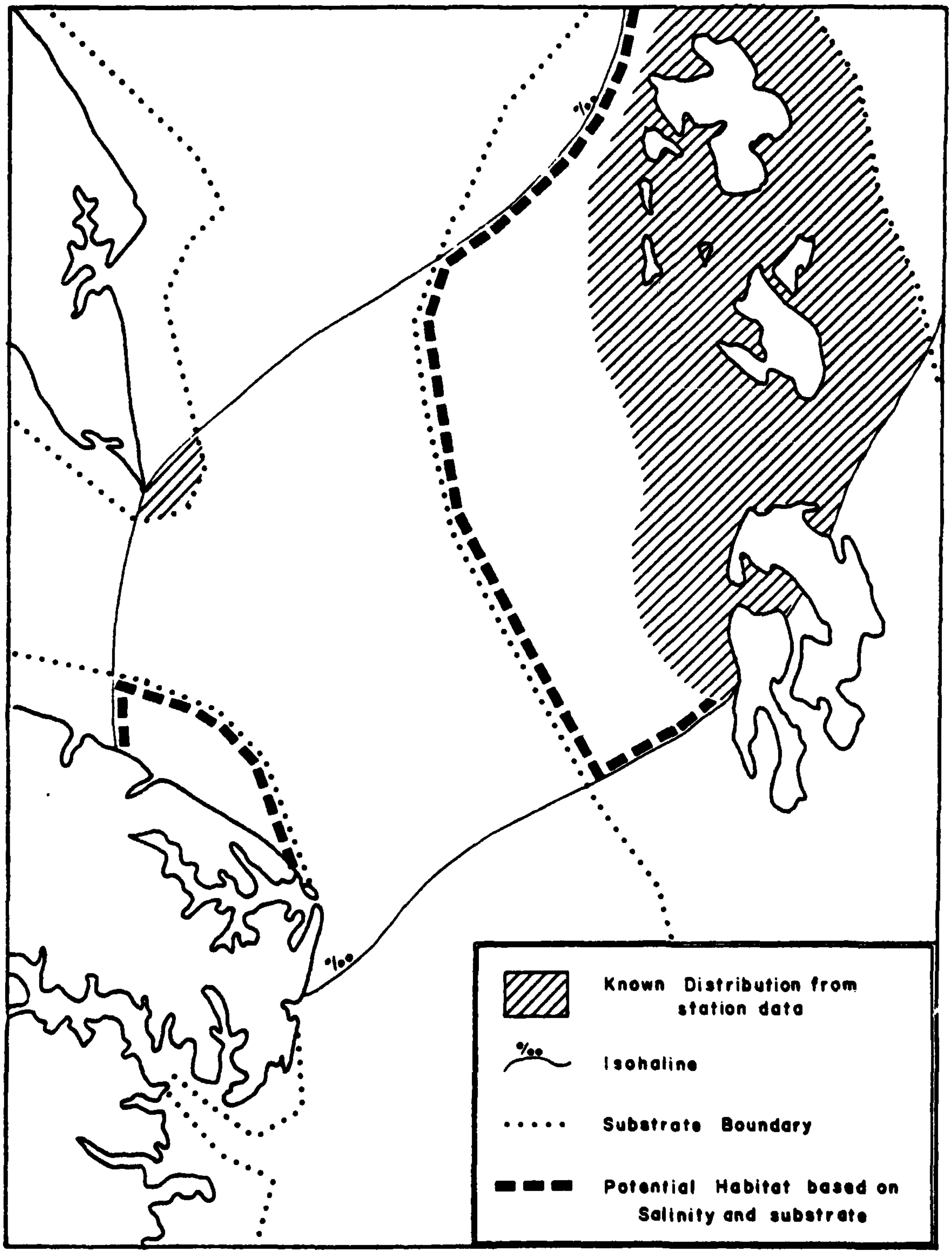

Figure IV - 17 KNOWN AND POTENTIAL HABITAT OF HYPOTHETICAL BENTHIC ORGANISM BASED ON STATION DATA, SUBSTRATE AND SALINITY

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